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EVALUATION OF EXTENDED AERATION TREATMENT AT RECREATION AREAS

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EVALUATION OF EXTENDED AERATION TREATMENT AT RECREATION AREAS, Progress Report,

B. David Clark

Federal Water Pollution Control Administration, Northwest Region, Corvallis, Oregon, Pacific Northwest Water Laboratory

FWPCA Program 15010---03/70

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The objectives are to define basic waste characteristics from recreation areas, evaluate existing treatment processes and to develop a guide for the planning and design of wastewater treatment facilities at recreation areas. The two winter recreation areas included Timberline Lodge on Mt. Hood, approximately 50 miles east of Portland, Oregon, and Crystal Mountain Ski Area near Mt. Rainier National Park, approximately 50 miles east of Tacoma, Washington. The two summer areas included Sunset Bay State Park, also on the Oregon coast, approximately five miles north of Bandon. Conclusions were: Overall design of extended aeration activated sludge systems treating the highly variable recreation wastewater will result in low organic loadings during low flow periods that may result in an inefficient system due to pH problems, nitrification-denitrification, reduced organic removal rate, and a highly dispersed aeration sludge with poor settling characteristics. A peak flow rate, on the order of 10 times the average daily flow, should be considered in the design of final clarifiers treating recreation wastewaters due to the possibility of carryover of suspended solids at the higher peak flow rates. The organic removal rate in terms of COD is highly dependent on stable pH conditions in the aeration basin of a biological system and may be severely reduced if conditions are not stable. The sludge synthesis ratio is not seriously affected by unstable low pH conditions. (Continued on next page)

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*State Parks, *Summer sports, *Extended aeration, Sunset Bay St Park (Ore) Crystal Mt.(Wash), Mt. Hood (Ore),

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It is recommended that, where secondary treatment is the desired standard, the use of extended aeration activated sludge systems for the treatment of recreation wastes be discouraged unless adequate assurance can be given that the plant will be properly operated and maintained, including proper sludge wasting facilities and/or an adequately designed solids removal process is added to the system either in the form of a polishing pond or a filtration unit. (see also W72-07247)

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EVALUATION OF EXTENDED AERATION TREATMENT AT RECREATION AREAS

Progress Report

A Technical Projects Report

Prepared by

B. David Clark
Regional Research Studies

Report No. PR-8

United States Department of the Interior
Federal Water Pollution Control Administration, Northwest Region
Pacific Northwest Water Laboratory
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A Working Paper presents results of investigations which are to some extent limited or incomplete. Therefore, conclusions or recommendations--expressed or implied--are tentative.

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ABBREVIATIONS

T	-	Temperature, °C
BOD_5	-	Five-day Biochemical Oxygen Demand, mg/l
COD	-	Chemical Oxygen Demand, mg/l
SS	-	Suspended Solids, mg/l
VSS	-	Volatile Suspended Solids, mg/l
TPO_4	-	Total Phosphate, mg/l as P
OPO_4	-	Ortho Phosphate, mg/l as P
TKN	-	Total Kjeldahl Nitrogen, mg/l as N
NH_3	-	Ammonia Nitrogen, mg/l as N
NO_2	-	Nitrite Nitrogen, mg/l as N
NO_3	-	Nitrate Nitrogen, mg/l as N
L_o	-	Influent BOD_5, mg/l
L_e	-	Effluent BOD_5, mg/l
L'_o	-	Influent COD, mg/l
L'_e	-	Effluent COD, mg/l
MLVSS=S_a	-	Aeration Tank Mixed Liquor Volatile Suspended Solids, mg/l
t	-	Aeration Tank Detention Time, days
S_e	-	Effluent VSS, mg/l
T'	-	Sludge Age, defined as lb MLVSS/lb VSS wasted per day
M	-	BOD_5 Removal Rate, lb BOD_5 Removed/lb MLVSS-day = $L_o - L_e / S_a t$
M'	-	COD Removal Rate, lb COD Removed/lb MLVSS-day = $L'_o - L'_e / S_a t$
a	-	Sludge Synthesis Ratio, lb VSS Produced/lb BOD_5 Removed
F	-	BOD_5 Organic Loading Rate, lb BOD_5/lb MLVSS-day = $L_o / S_a t$

ABBREVIATIONS (Continued)

F'	-	COD Organic Loading Rate, lb COD/lb MLVSS-day = $L_o'/S_a t$
a'	-	Sludge Synthesis Ratio, lb VSS Produced/lb COD Removed
b	-	Endogenous Respiration Rate, lb VSS Destroyed/day/lb MLVSS
~~Z~~	-	Positive or Negative BOD_5 or COD Removal Constant Depending on Substrate
R	-	Linear Regression Analysis Correlation Coefficient
K	-	BOD_5 Removal Rate Coefficient, day^{-1}
K'	-	COD Removal Rate Coefficient, day^{-1}
Θ	-	van't Hoff Arrhenius Temperature Relationship Coefficient $K_{20}=K_T\Theta^{T-20}$
b_{max}	-	Maximum Endogenous Respiration rate, day^{-1}
Φ	-	Rate of Decay of the Endogenous Respiration rate, day^{-1}
SVI,	-	Sludge Volume Index
DO	-	Dissolved oxygen, mg/l
Hp	-	Horsepower
gpd	-	gallons per day
pH	-	negative logarithm of the hydrogen ion concentration
Avg	-	average
c	-	subscripts refer to centrifugal values
t	-	refers to total value

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INTRODUCTION

Problem

With the trend toward complete water systems and the rapid present and expected future growth in recreational activities, the disposal of waste waters from recreation areas has become a major problem in certain areas and is of concern in all areas with significant recreation use.

The federal nondegradation policy which, as stated in the Guidelines for Establishing Water Standards for Interstate Waters[1/], says that "In no case will standards providing for less than existing water quality be acceptable." This has since been interpreted to allow some degradation where economically justified but generally can be taken as originally stated.

This policy has a direct effect on the treatment of waste-water from recreation areas in that it demands essentially complete treatment of all wastes discharged to a water body. In order to provide this high level of treatment, sound design criteria must be developed on the basic characteristics of waste waters from recreation areas and treatment processes that will function under extreme loading and temperature conditions and remote areas that may receive little or no routine operation and maintenance.

Generally, most recreation areas can rely upon the septic tank and drain-field system of disposal with little or no concern about direct resultant effects on water quality. However, for many of the more sophisticated camping areas that have water systems (flush

toilets, showers, and in some cases complete laundry facilities) the soil conditions are completely inadequate to take the higher volume of wastewater and alternative methods of disposal must be used. In many instances, package extended aeration treatment plants have been selected for treatment because of their low cost, high efficiency and ease in operation and maintenance. Whether or not they are efficient and easy to operate and maintain has been questioned.

Purpose and Scope

In order to develop basic information and guidelines for use in the treatment of wastes from recreation areas, the Recreational Sites Waste Treatment Project was initiated in August 1967 at the request of the Washington State Water Pollution Control Commsssion and strongly supported by other state and federal agencies. The study will be terminated in January 1970.

Specifically, the objectives of the study are to define basic waste characteristics from recreation areas, evaluate existing treatment processes and to develop a guide for the planning and design of wastewater treatment facilities at recreation areas. The study is being conducted in essentially three phases:

Phase I: Winter Recreation Area Surveys

Phase II: Summer Recreation Area Surveys

Phase III: Pilot Plant Studies

A progress report has been published on the basic waste characteristics at winter recreation areas[1/].

This paper summarizes the findings of studies conducted under both Phase I and II to evaluate existing extended aeration treatment processes, and attempts to define the performance of these plants under various temperature and loading conditions and to provide basic information on the biological kinetics necessary for the design of an extended aeration type biological treatment system for recreation wastewaters.

Authority

Section 5 of the Federal Water Pollution Control Act, as amended, authorizes the Secretary of the Interior to conduct special studies on water pollution problems at the request of a state or other public agency. The State of Washington has made such a request through a letter dated July 24, 1967, to the Federal Water Pollution Control Administration.

The Secretary of the Interior is also authorized through Executive Order 11288 to assist other Federal agencies in the abatement and prevention of water pollution.

Study Area

Four sites, two winter sport areas and two summer camping areas, were selected in Oregon and Washington for study because of their accessibility and close proximity to the Pacific Northwest Water Laboratory in Corvallis, Oregon.

The two winter recreation areas included Timberline Lodge on Mt. Hood, approximately 50 miles east of Portland, Oregon, and Crystal Mountain Ski Area near Mt. Rainier National Park, approximately 50 miles east of Tacoma, Washington. The two summer areas included Sunset Bay State Park on the Oregon Coast, approximately 10 miles southwest of Coos Bay, and Bullards Beach State Park, also on the Oregon coast, approximately five miles north of Bandon. Figure 1 illustrates the location of these areas.

FIGURE I. STUDY AREA

SUMMARY

Findings

1. At the two ski areas, Timberline Lodge and Crystal Mountain, hydraulic and organic loadings were highly variable and extremely low when compared to normal loadings for extended aeration treatment. However, at the two summer areas, Bullards Beach and Sunset Bay, both hydraulic and organic loadings were fairly constant due to fairly consistent use, large amounts of infiltration and high collection system detention times.

2. The organics removal efficiency from all four plants studied in terms of BOD_5 and COD was highly variable and on an average basis less than that considered for secondary treatment, i.e. 85 percent removal. At the two ski areas, the average BOD_5 removal efficiencies were 80 and 84 percent with a range from 0 to over 97 percent. At the two summer areas, the average BOD_5 removal efficiency was 62 and 73 percent and ranged from 34 to 89 percent.

3. The SS removal efficiency was also highly variable at all four plants and varied from less than 0 percent to approximately 90 percent, with an average value of 58 percent for the ski areas and 66 percent for the summer areas. Floating sludge in the final clarifier was noted on several occasions at both Crystal Mountain and Timberline Lodge.

4. The effluent suspended solids was found to vary directly with the SVI and inversely with the organic loading over the

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range of values encountered in this study. At loading levels below 0.1 lb COD/lb MLVSS-day, the SVI increased rapidly with a concurrent rise in effluent SS.

5. There was a significant reduction in alkalinity through all four systems studied which generally corresponded with increased nitrification. It was also noted that the raw sewage alkalinity at the two ski areas during weekday operation was considerably less than the average weekend values.

6. At the two ski areas, the pH in the aeration basins and final effluent decreased significantly, and was extremely variable with 100 percent changes noted overnight. At the two summer areas, the effluent pH was low (<6.0) but not as variable as at the ski areas.

7. Microscopic analysis of the aeration basin activated sludge at the two ski areas indicated a highly dispersed floc with active protozoan populations and large numbers of filamentous fungi. The fungi was identified as Geotrichum condidum at Crystal Mountain.

8. Percent nitrification through the four systems studied was significantly less than reported in the literature for similar organic loading conditions.

9. The organic removal rate was calculated on the basis of completely mixed activated sludge theory, assuming a rate

proportional to the soluble effluent concentration. COD data were used for this determination because of the high degree of nitrification in the effluent of the four plants studied and its effect on the BOD_5 test. This total relationship was assumed to be $M' = K'L'_e \pm Z$ (terms are defined in Abbreviations).

10. For the properly buffered systems, the COD removal rate$^{(K')}$ was calculated as 0.017/day at 20°C. For the low, variable pH systems, the rate was considerably lower, approximately 1/8 that of the normal system, at 0.0022/day at 20°C.

11. The Z term in the total organic removal relationship was calculated as -0.078 for the properly buffered systems and -0.072 for the variable pH systems. The negative sign of this term indicates a nonbiodegradable portion of the influent waste.

12. The rate of sludge production was calculated assuming steady state conditions, a sludge regrowth rate directly proportional to substrate concentration, and a variable endogenous respiration rate dependent on sludge age and temperature. This gave the relationship

$$1/_{T'} = aM - b_{max}e^{-\Phi T'}$$

(terms are defined in Abbreviations).

13. The sludge synthesis ratio, a, was calculated as 0.54 lb VSS Produced/lb BOD_5 removed or 0.33 lb VSS Produced/lb COD removed.

14. The maximum endogenous respiration rate, b_{max}, was calculated as 0.052/day at 20°C with a decay coefficient, Φ, of 0.02/day.

Conclusions

1. Overall design of extended aeration activated sludge systems treating the highly variable recreation wastewater will result in low organic loadings during low flow periods that may result in an inefficient system due to pH problems, nitrification-denitrification, reduced organic removal rate, and a highly dispersed aeration sludge with poor settling characteristics.

2. A peak flow rate, on the order of 10 times the average daily flow, should be considered in the design of final clarifiers treating recreation wastewaters due to the possibility of carryover of suspended solids at the higher peak flow rates.

3. The organic removal rate in terms of COD is highly dependent on stable pH conditions in the aeration basin of a biological system and may be severely reduced if conditions are not stable.

4. The high correlation coefficients obtained through linear regression analysis of the COD removal data appears to

5. The sludge synthesis ratio (a) is not seriously affected by unstable low pH conditions.

Recommendations

Where secondary treatment is the desired standard, the use of extended aeration activated sludge systems for the treatment of recreation wastes should be discouraged unless adequate assurance can be given that the plant will be properly operated and maintained, including proper sludge wasting facilities and/or an adequately designed solids removal process is added to the system either in the form of a polishing pond or a filtration unit.

STUDY PROCEDURES

Flow Measurement

At Crystal Mountain, flow to the treatment plant was measured with a 60° V-notch weir installed on the effluent side of the plant clarifier. A water stage recorder* with a three-day chart was used to record the weir height which was then converted to flow. The recorder was installed on January 12, 1967, and removed on April 29, 1968.

At Timberline Lodge, wastewater flow is measured continuously by a 22.5° V-notch weir on the effluent side of the plant chlorine contact chamber. The recorder is equipped with a totalizer which was read daily during each survey period.

At Bullards Beach State Park, a water stage recorder* was installed in the wet-well of a small pump station that precedes the treatment plant. Flow was calculated from water stage differences and a known volume-stage relationship. This recorder was installed in May 1968 and removed in October 1968.

At Sunset Bay State Park, a totalizing flow meter at a pump station preceding the treatment plant was read daily during the survey period at the time of sample collection.

*Leopold-Stevens Type F Recorder. Use of product and company names is for identification only and does not constitute endorsement by the U. S. Department of the Interior or the Federal Water Pollution Control Administration.

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Sampling

Two surveys were made at Timberline Lodge from January 20-29, 1968 and May 10-13, 1968. Samples were collected from the influent sewer, aeration basins, and clarified effluent.

Grab samples of the raw wastewater were collected every hour using an automatic sampler and then composited proportional to flow.

Grab samples of each aeration basin were collected once per day and mixed in equal proportions.

The clarified effluent sample was collected using an automatic sampler constructed at the Pacific Northwest Water Lab. This device consisted of a small pump operating continuously. The flow passed through a double chambered funnel with a solenoid valve that operated off a recycle timer. Every minute for five seconds, the timer activated the solenoid which directed the flow into an iced sampling container. Figure 2 illustrates this sampling apparatus.

Three surveys were made at Crystal Mountain from February 11-19, March 8-12, and April 26-29, 1968. During the March 8-12 survey, the National Alpine Ski Championship was being held at the Crystal Mountain area. Composite samples were collected from the raw wastewater and clarifier effluent and a daily grab sample was collected from the aeration tank. The method of sampling was the same as that used in the Timberline Lodge surveys.

Single surveys were made at Bullards Beach and Sunset Bay State Parks both during the period from June 14-20, 1968. Samples

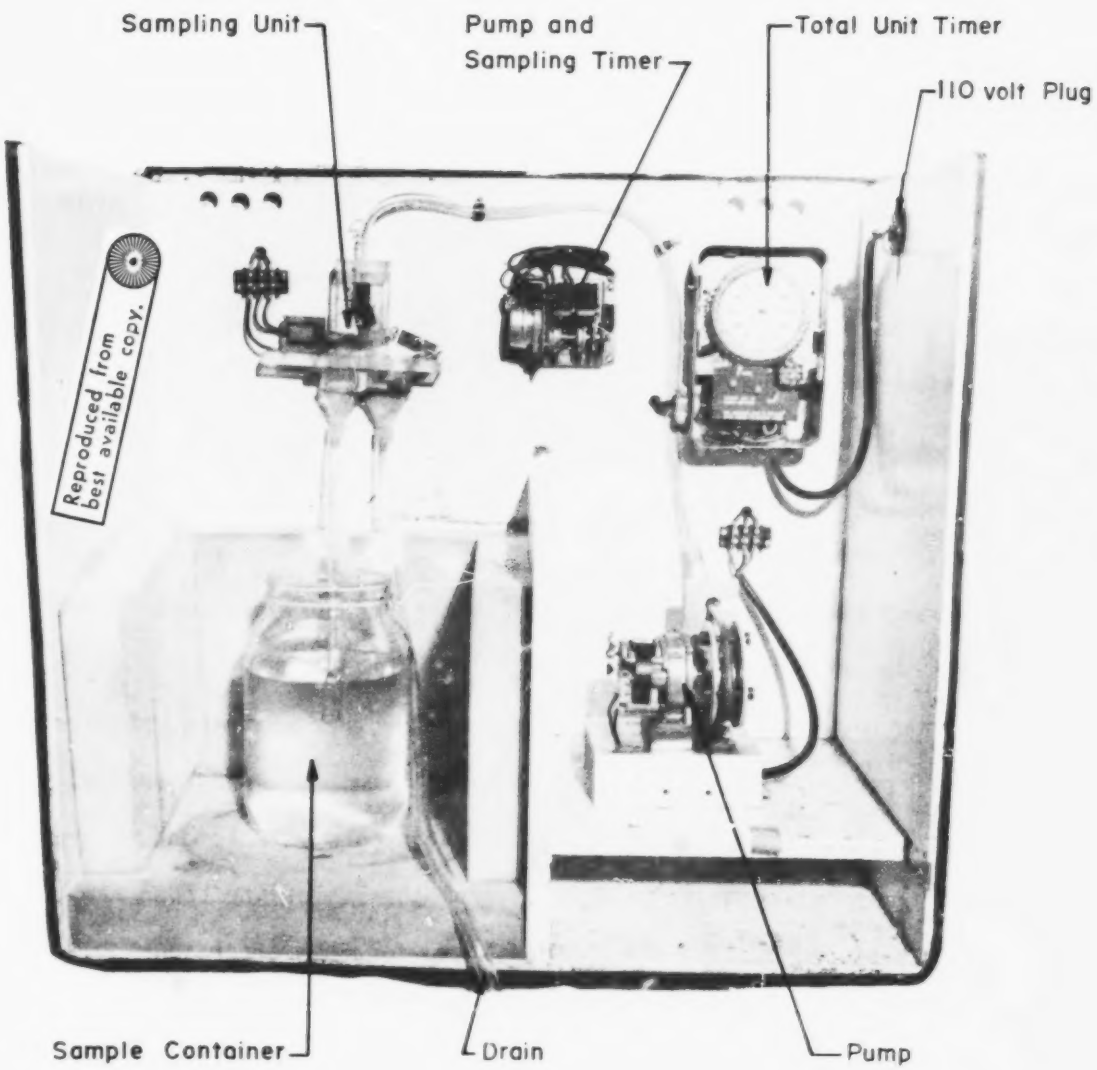

FIGURE 2. SAMPLING UNIT

were collected daily from the raw wastewater, aeration basin and clarified effluent. The raw wastewater sample at both areas was collected and composited automatically using the device shown in Figure 2. This sampler is similar to the pump sampler described previously, except that the unit can be battery operated. The unit was programmed to collect sample volumes in proportion to the average flow distribution at each area. The aeration tank sample was a grab sample collected once per day, and the final clarifier sample was collected in the same manner as described previously for the Timberline Lodge surveys.

All samples were iced during collection and while in transit to the Pacific Northwest Water Laboratory in Corvallis, Oregon. Samples for COD analysis were preserved with concentrated sulfuric acid and samples for nitrogen and phosphorous analysis were preserved with mercuric chloride.

Unpreserved samples were used for all other analyses. Analysis of unpreserved samples for BOD_5 occurred within a 24-hour period. In order to check the change in BOD_5 during sample shipment, a grab sample was collected on January 12 from the Timberline Lodge raw sewage, stored at 5°C, and then analyzed for BOD_5 after four hours and 28 hours. There was less than 10 percent difference in the values which is within the accuracy of the BOD_5 test.

Analysis

All laboratory analyses, with the exception of centrifuged BOD_5 and COD, TPO_4 and OPO_4, were performed in accordance with the

12th Edition of Standard Methods[2/]. Field analyses were made for temperature, D.O., pH, and percent solids in the aeration basin. D.O. and pH were measured using battery-operated probes. Percent solids was measured in accordance with Standard Methods.

PLANT DESCRIPTIONS

Each of the systems is described below with pertinent details given regarding the types and sizes of facilities available and the type of area served. Figure 3 also illustrates the flow diagram of each system.

Crystal Mountain

The treatment system at this area presently serves only a portion of the total facilities which includes a day lodge, administration building and two overnight lodges.

Treatment consists of screening, comminution, complete mix, biological aeration, clarification with return sludge facilities and final disposal to a subsurface drain field. Aeration is provided by a mechanical surface aerator on a timed basis. Table 1 gives pertinent details regarding volumes and capacities for this system.

TABLE 1
DETAILS OF CRYSTAL MOUNTAIN TREATMENT SYSTEM

Facility	Description
AERATION TANK	Square concrete construction
Dimension	21' x 21' x 11 1/4'
Volume	37,000 gallons
Aerator	10 Hp mechanical aerator
CLARIFIER	Circular radical flow
Surface area	201 ft.^{2}
Volume	14,850 gallons
Overflow weir length	47 ft.
SLUDGE RETURN	Air lift pump

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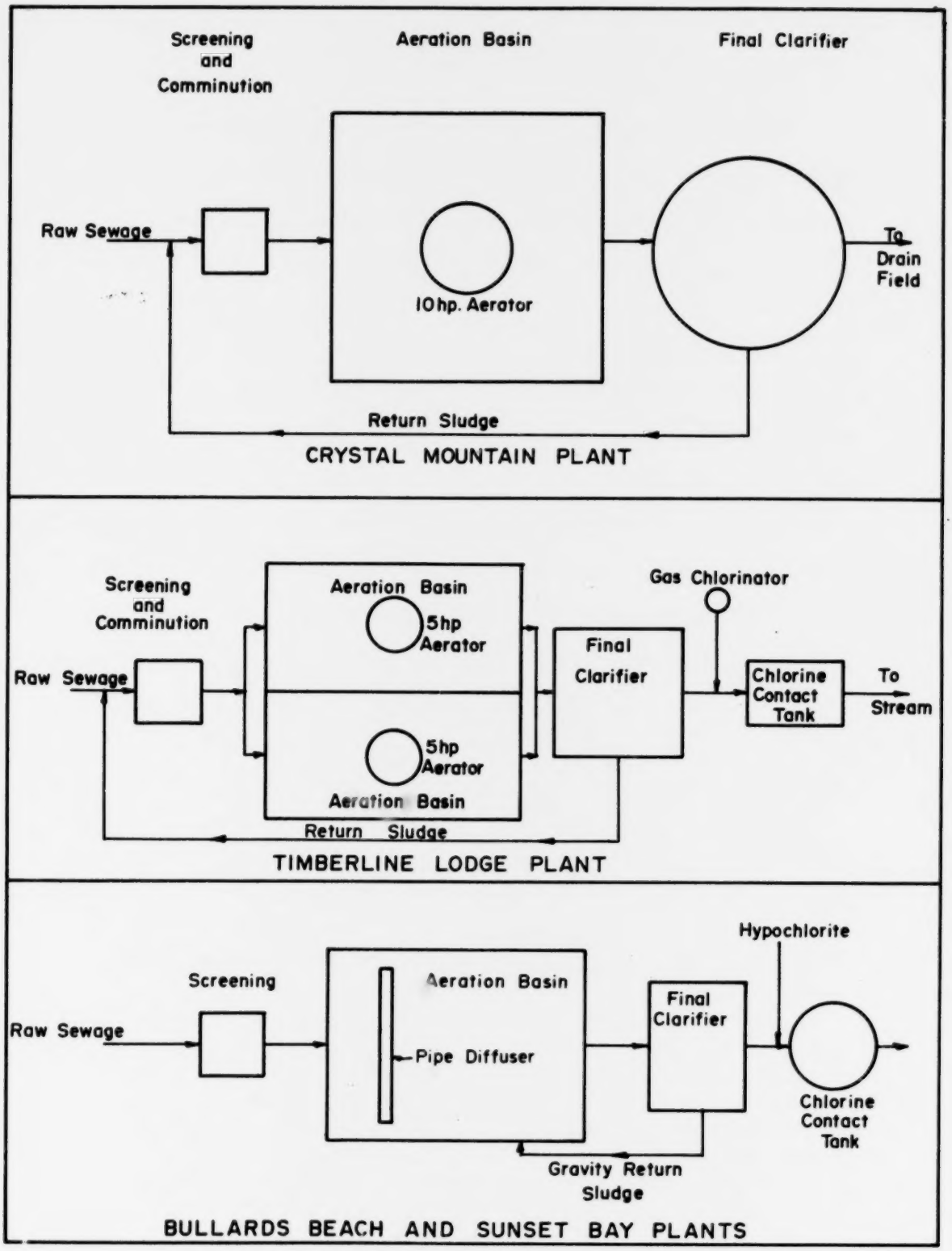

FIGURE 3. TREATMENT PLANT FLOW DIAGRAMS

Timberline Lodge

The treatment system at this area serves all facilities at the ski area which essentially includes only a combined overnight-day lodge with a restaurant and lounge.

The treatment system consists of screening and comminuting the raw sewage, secondary biological treatment in two 30,000 gallon aeration tanks each with a 5 Hp mechanical surface aerator, secondary clarification, chlorination of the final effluent with a gas chlorinator and baffled chlorine contact chamber. Like Crystal Mountain, the aerators at this plant are on a timed basis. Table 2 gives pertinent details of this system.

TABLE 2

DETAILS OF TIMBERLINE LODGE SYSTEM

Facility	Description
AERATION TANK	2 - 19' x 19' x 12' concrete tanks
Volume	30,000 gallon/tank
Aeration	2 - 5 Hp mechanical aerators
CLARIFIER	Rectangular concrete basin 19' x 6' x 12'
Volume	11,050 gallons
Surface Area	114 ft.
Overflow weir length	12 ft.
Chlorine contact chamber	Rectangular basin with over-under redwood baffles
Volume	2,175 gallons

Bullards Beach

The treatment system at this area serves the overnight campground with 128 camp sites and a day-use area with a single bathhouse.

Treatment is provided by a small extended aeration package plant with a capacity of 11,000 gallons per day (gpd). The package plant provides screening, aeration with diffused aerators, clarification with sludge return by gravity and chlorination prior to discharge to the Coquille River.

Table 3 gives pertinent details of the system.

TABLE 3
DETAILS OF BULLARDS BEACH SYSTEM

Facility	Description
AERATION	
Volume	11,000 gallons
Aerators	Pipe diffusors with air compressors
CLARIFICATION	
Volume	920 gallons
Surface area	40 ft.^{2}

Sunset Bay

The treatment system at this area receives the septic tank effluent from an overnight campground with 137 camp sites, and a large day-use area.

The treatment plant is also a packaged extended aeration system with 17,000 gpd capacity of the same type as that at Bullards Beach. After chlorination, the effluent is discharged to the Pacific Ocean.

Pertinent details are given in Table 4.

TABLE 4

DETAILS OF SUNSET BAY SYSTEM

Facility	Description
AERATION TANK	
Volume	17,000 gallons
Aerator	Diffused aerators
CLARIFIER	
Volume	1,430 gallons
Surface area	60 ft.^{2}

RESULTS

Pertinent analytical and field data is summarized for each area in Table 5 and complete data is provided in the Appendix. Figure 4 illustrates the variation in aeration detention time and organic loading at each of the four plants studied.

Hydraulic Loadings

Data on the hydraulic loading is presented in Table 6 in terms of average daily theoretical detention time in the aeration basin and the hydraulic surface loading on the final clarifiers.

For the two ski areas, the aeration detention time was highly variable and on an average basis, considerably greater than normally found in extended aeration treatment. At Timberline Lodge, the detention time varied from 3.8 to 15.8 days with an average of 8.9 days for the two survey periods. The average detention time for the weekdays monitored (weekdays are considered as 9:00 am Tuesday through 9:00 am Friday) was approximately 11.5 days while the average for weekends (9:00 am Saturday through 9:00 am Monday)* was 6.0 days. The most severe shock load in terms of daily change was from 10.4 to 3.8 days or approximately a three-fold increase in flow. At Crystal Mountain, the detention time varied from 0.8 to 14.3 days with an average of 3.6 days for the three survey periods. The average for the weekdays monitored was 6.2 days and 2.8 days for the weekends.

*Monday is considered as part of the weekend because flows were measured from 9:00 am to 9:00 am and the flow measured Monday would include flows from Sunday.

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TABLE 5

ANALYTICAL DATA SUMMARY

Period	Location	BOD Mg/l Total	BOD Mg/l Filtered	COD Mg/l Total	COD Mg/l Filtered	SS Mg/l	VSS Mg/l	TPO_4 Mg/l	TKN Mg/l	NH_3 Mg/l	NO_3+NO_2 Mg/l	Alk Mg/l	pH	Temp °C	SVI	Average flow,gpd
Timberline	Inf	485	250	833	380	470	410	13.2	71.10	43.5	0.30	247	7.2		--	8,720
Lodge	Aer	--	--	--	--	2150	1885	--	--	--	--	75	5.7	10.5		
1/21-29	Eff	70	13	230	67	145	125	10.2	26.9	12.5	27.76	61	5.3			
Timberline	Inf	320	--	580	--	171	149	11.4	44.1	13.6	0.33	133	6.2	--	--	7,625
Lodge	Aer	--	--	--	--	2025	1865	--	--	--	--	80	5.7	10.1	380	
5/10-13	Eff	47	16	172	74	86	75	10.3	15.6	2.9	10.2	13	5.2	--	--	
Crystal	Inf	400	--	953	--	405	367	16.6	91.2	29.1	0.35	320	6.4	--	--	9,250
Mountain	Aer	1730	32.2	4128	218	3599	3154	--	262	47.0	30.60	170	6.7	3.6	146	
2/11-19	Eff	135	18.6	216	89	222	191	11.5	59	31.9	28.40	93	6.7	--	--	
Crystal	Inf	228	--	470	--	282	246	7.9	54.1	11.4	0.18	212	6.8	--	--	23,100
Mountain	Aer	2550	64.2	3850	--	3390	2990	--	153	21.0	10.10	133	6.6	6.0	248	
3/8-12	Eff	80	26.6	206	77	121	97	7.1	32.3	19.7	10.90	35	6.6	--	--	
Crystal	Inf	393	--	650	--	395	385	11.3	86.3	15.4	0.35	252	6.8	--		7,000
Mountain	Aer	1211	32.8	5450	236	4260	3950	--	226	26.3	45.20	120	6.2	5.0	372	
4/26-29	Eff	51	18.0	195	53	120	108	10.0	34.5	26.0	45.60	11	5.7			
Bullards	Inf	79	--	220	--	75	--	5.2	46.32	39	0.03	195	7.1	--		
Beach	Aer	--	--	--	--	997	--					43	6.1	15.7	67	7,900
6/11-20	Eff	30	10.4	53	25	25		2.6	14.87	12.74	22.19	3	5.4	--		
Sunset	Inf	92	--	188	--	59	--	8.3	73.73	65.8	0.03	282	7.3	--		
Bay	Aer	--	--	--	--	717	--					54	6.5	13.4	48	12,870
6/14-20	Eff	22	64	41	19	20	--	6.8	24.77	27.46	38.74	4	5.3	--		

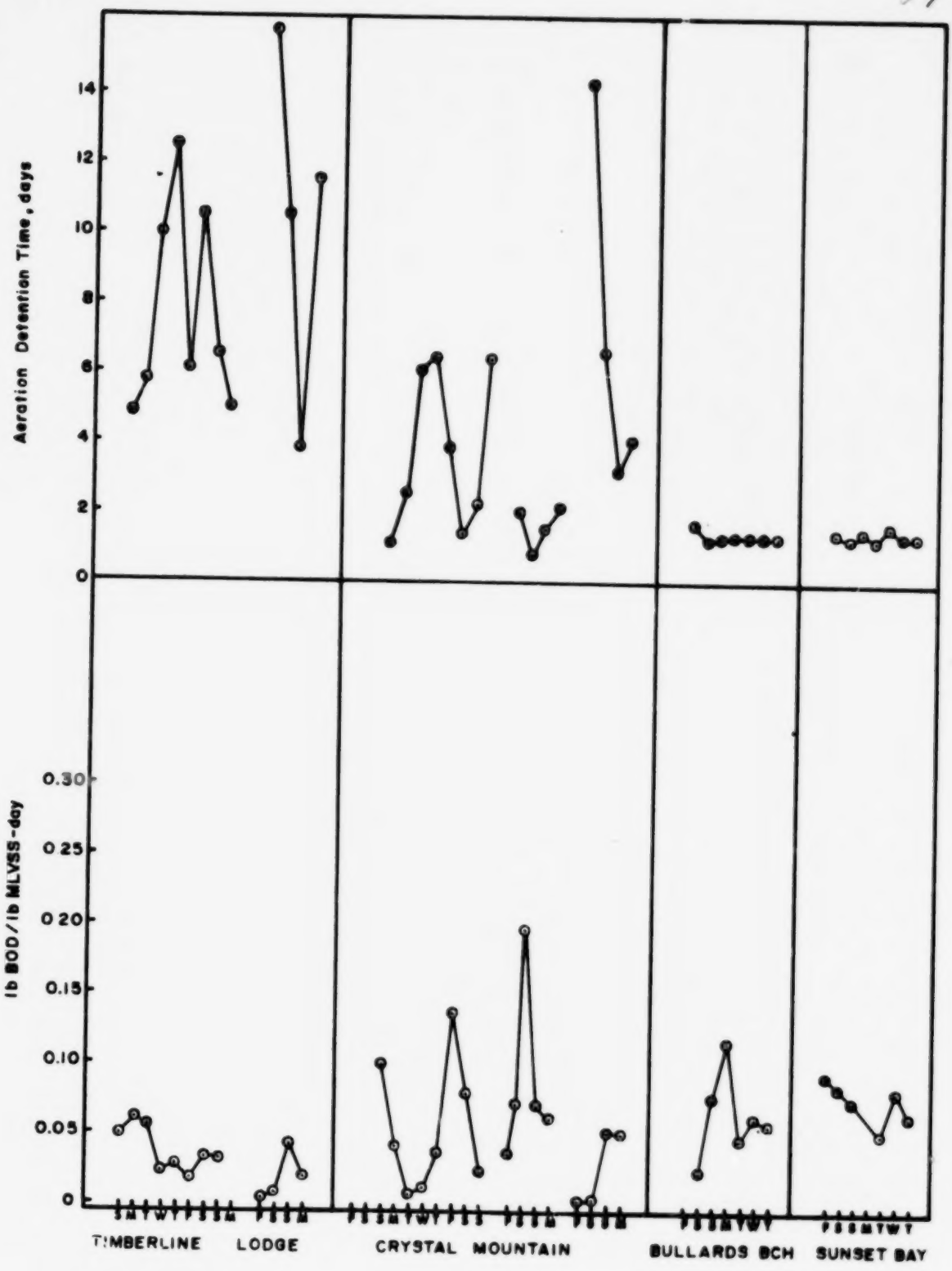

FIGURE 4. HYDRAULIC AND ORGANIC LOADINGS

TABLE 6

SUMMARY OF HYDRAULIC AND ORGANIC LOADINGS

Loading	AREA							
	Timberline		Crystal		Bullards Beach		Sunset Bay	
	Average	Range	Average	Range	Average	Range	Average	Range
Detention Time, Days	8.9	3.8-15.8	3.6	0.8-14.3	1.3	1.2-1.6	1.3	1.2-1.6
Clarifier Surface Loading, gpd/ft^2	61	33-139	65	12-234	210	--	210	--
lb BOD/ lb MLVSS-day	0.031	0.004-0.062	0.048	0.002-0.136	0.056	0.025-0.116	0.065	0.055-0.093
lb BOD/ 1000 ft^3/day	3.0	--	6.5	--	4.2	--	3.8	--
Ratio of average weekend loading to average weekday loading	1.3	1.5-6.0	3.2	2.0-17.0	--	--	--	--

The hydraulic loading on the final clarifiers at the two ski areas was equally as variable as the aeration detention time. At Timberline Lodge, the average daily rate varied from 33 to 139 gpd/ft^2 and at Crystal Mountain from 12 to 234 gpd/ft^2.

These values are not unusually high on the basis of normal design rates of 400-600 gpd/ft^2, but it should be remembered that they are average daily rates, whereas, design is on the basis of peak rates. On the basis of peak flows, which are on the order of ten times the average daily flow rate[1/], the maximum surface loadings would be 1,390 gpd/ft^2 for Timberline Lodge and 2,340 gpd/ft^2 for Crystal Mountain, both of which exceed design values.

The hydraulic loadings found at both the summer parks, Sunset Bay and Bullards Beach, were quite constant during all days of the survey period with a total range in aeration detention times from 1.2 to 1.6 days and an average surface loading on the final clarifiers of approximately 210 gpd/ft^2. The reason for the constant loading at Bullards Beach is attributed primarily to an extremely high rate of infiltration. It is estimated that there was over 5,000 gpd of infiltration to the system during the survey period which accounts for 60-70 percent of the entire wastewater volume. This high rate tends to dampen any fluctuations from wastewater contributed through actual camper use. The constant flow at Sunset Bay is attributed to detention time in the collection system prior to being pumped to the plant and infiltration. Each rest station at this area has a septic tank

that precedes the actual wastewater discharge to the treatment plant. The combination of long collection system detention time and infiltration tend to dampen any hydraulic loading fluctuations.

Organic Loadings

The organic loading on all four systems studied was quite low for extended aeration biological systems. Normally, an F value of 0.1 to 0.2 lb BOD_5/lb MLVSS-day is used in design. In terms of volumetric capacity, this would be on the order of 15-20 lb BOD_5/1,000 ft^3 of aeration capacity. At the two ski areas, the average organic loadings were quite low compared to the normally used design values and were highly variable on a day to day basis. Timberline Lodge loadings were less variable than those at Crystal Mountain due to the more consistent usage at this area. At Timberline Lodge, the average organic loading, F, was 0.031 with a range from 0.004 to 0.062. It can be noted that even the highest loading found was well below the average design value of 0.10. The difference between weekend and weekday loadings was not as great as might be expected from a ski area with a ratio of 1.3 for the average weekend to average weekday loading. At Crystal Mountain, the organic loading, F, averaged 0.048 with a range from 0.002 to 0.136. There was considerable variation from weekday to weekend loadings as indicated by the average ratio of 3.2 with a value as high as 17 noted on one occasion. In terms of volumetric loadings, the average values were 3.0 and 6.5 lb BOD_5/1,000 ft^3 for Timberline Lodge and Crystal Mountain, respectively.

The organic loading at Bullards Beach and Sunset Bay were by comparison to the two ski areas quite consistent with respective average ratios of 0.056 and 0.065 and ranges from 0.025 to 0.116 and 0.055 to 0.093. There was little difference noted between weekdays and weekends. The average lb BOD_5/1,000 ft^3 ratio was 4.2 for Bullards Beach and slightly lower at 3.8 for Sunset Bay. Like the two ski area systems, both Bullards Beach and Sunset Bay are underloaded on an average basis.

System Efficiencies

The efficiency of all four plants studied on the basis of BOD_5, COD and SS was quite variable as shown by Table 7 and illustrated by Figure 5.

At Timberline Lodge, the average total BOD_5 removal efficiency was 84 percent with a range from 55 to 97 percent. The average COD removal efficiency was 71 percent and the average suspended solids removal was 59 percent with a range from 0 to 96 percent.

The Crystal Mountain system generally performed similar to the Timberline system with perhaps a little more variability. The average total BOD_5, COD and SS removals were 80, 70, and 57 percent, respectively. A high degree of variability, though, is indicated by the fact that the removal of all three parameters varied from actually less than 0 percent to over 90 percent.

TABLE 7

SUMMARY OF TREATMENT PLANT REMOVAL EFFICIENCIES

Parameter	Timberline Lodge		Crystal Mountain		Bullards Beach		Sunset Bay	
	Average	Range	Average	Range	Average	Range	Average	Range
% Total BOD_5	84	55-97	80	0-94	62	34-79	73	42-89
% Centrifuged BOD_5*	98	92-99	94	81-97	87	84-93	92	89-93
% Total COD	71.0	36-92	70	0-90	74	56-84	75	60-87
% Centrifuged COD*	90.0	75-94	89	76-96	86	82-91	90	88-92
% SS	59	0-96	57	0-95	67	0-85	66	0-89

*Based on comparison of total influent analysis to centrifuged effluent analysis

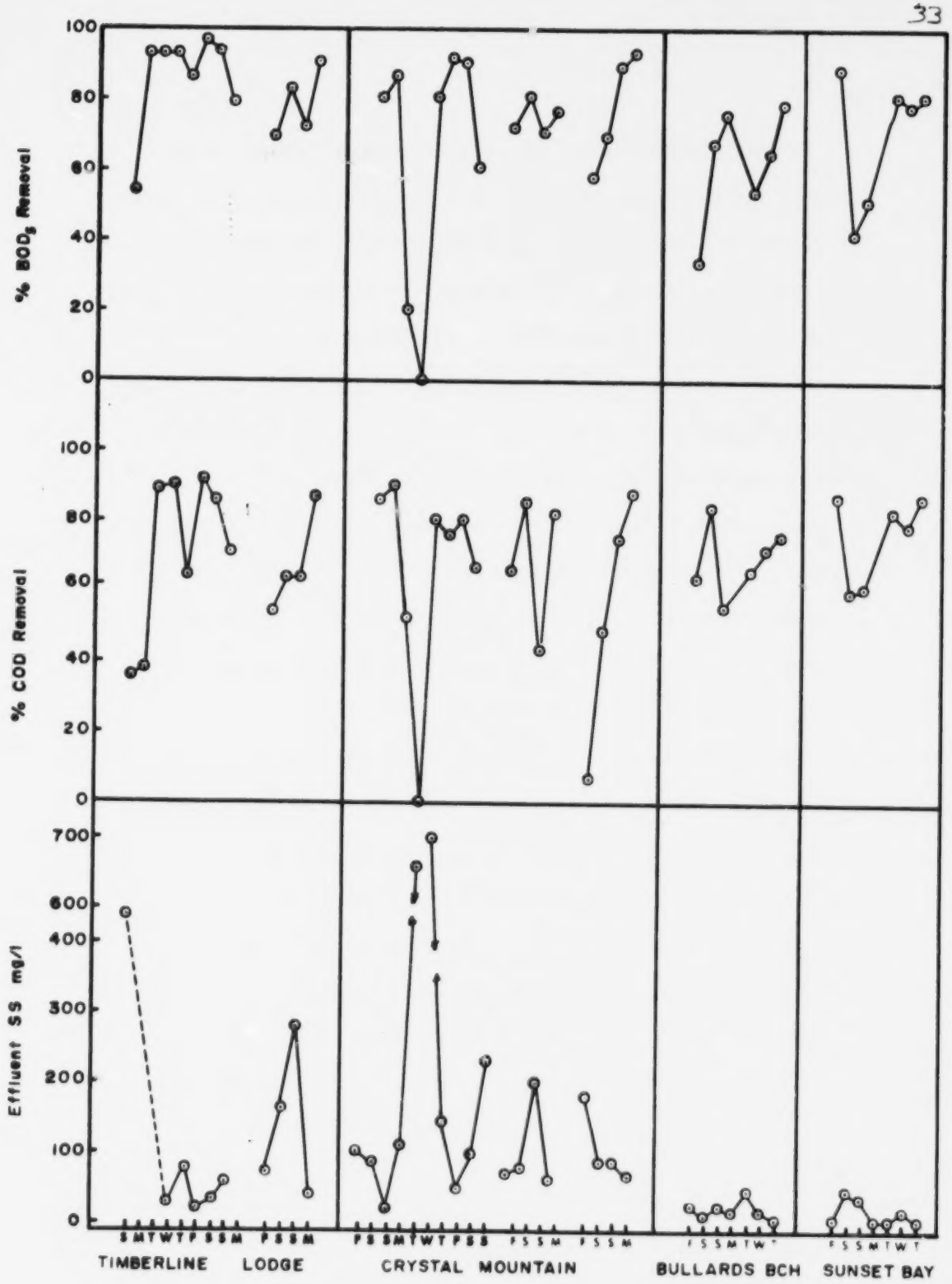

FIGURE 5. PERCENT BOD_5 AND COD REMOVALS AND EFFLUENT SS

Bullards Beach system had an average BOD_5 removal of 62 percent, a COD removal of 74 percent, and SS removal of 67 percent. The Sunset Bay system averaged 73 percent BOD_5 removal, 75 percent COD removal and 66 percent SS removal. The reason for the higher COD efficiency relative to BOD_5 is attributed to nitrification in the BOD_5 test on the effluent samples. Table 10 is a graph of the effluent BOD_5 versus COD, and illustrates this point by having a positive BOD_5 value when the COD is zero.

Also given in Table 7 is the percent efficiency for BOD_5 and COD removal based on centrifuged effluent samples. These data indicate that the BOD_5 and COD efficiency of the systems could be improved from 10-20 percent through more efficient removal of effluent suspended solids.

Figure 6 shows the COD loading versus percent COD removed on the basis of total effluent analysis and centrifuged effluent analysis. This figure also indicates the considerable effect of suspended solids carryover in the final effluent which becomes of greater significance as the loading decreases. It can be seen that if the loading decreases from 0.2 to 0.1 lb COD/lb MLSS-day, the efficiency based on total sample analysis decreases from 78 percent to 75 percent, but the efficiency based on centrifuged samples increases from 91 percent to 93 percent.

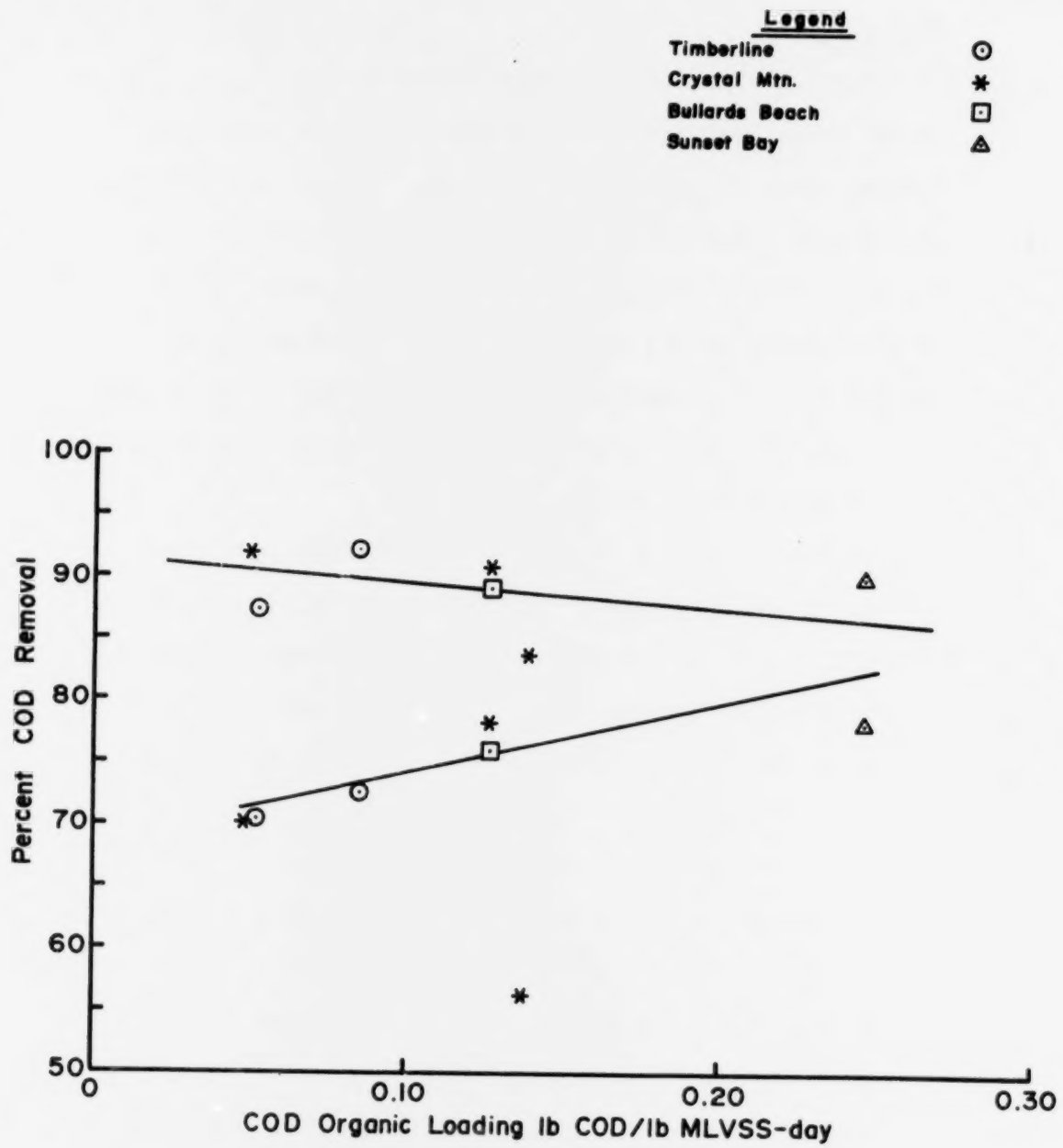

FIGURE 6. COD ORGANIC LOADING VS COD REMOVAL EFFICIENCY FOR TOTAL & CENTRIFUGED EFFLUENT SAMPLES

Figure 7 illustrates the relationship between sludge volume index (SVI), effluent suspended solids, and organic loading. Over the range of values encountered in these surveys, the effluent suspended solids was found to vary directly with SVI and inversely with organic loading. For example, if the organic loading was 0.1, the SVI would be approximately 130 and the effluent SS would be approximately 90 mg/l. If the organic loading was increased to 0.2, the SVI would decrease to 40 and the effluent SS would decrease to 20 mg/l.

It should be noted, though, that Figure 7 is based on an average of data obtained in each survey; and if the individual data points were plotted, there would be considerable scatter to the Timberline and Crystal data. The cause of this scatter is attributed to a floating sludge problem which was observed on several occasions at both plants. The problem was not noted at either Bullards Beach or Sunset Bay.

Table 8 gives data on the BOD_5 and COD values of the MLVSS for the Crystal Mountain system during the period of February 10-19 and April 26-29. During the first period, the data indicated average ratios of 0.54 mg BOD_5/mg VSS and 1.25 mg COD/mg VSS. During the second period, the BOD_5/VSS ratio had decreased to 0.3, but the COD/VSS ratio remained constant at 1.30. Corresponding sludge ages for these periods were 122 days and 190 days, respectively. The theoretical ratio for COD/VSS is approximately 1.4 and agrees quite closely with the data in Table 8. However, the ratio for BOD_5/VSS, which was expected to be on the order of

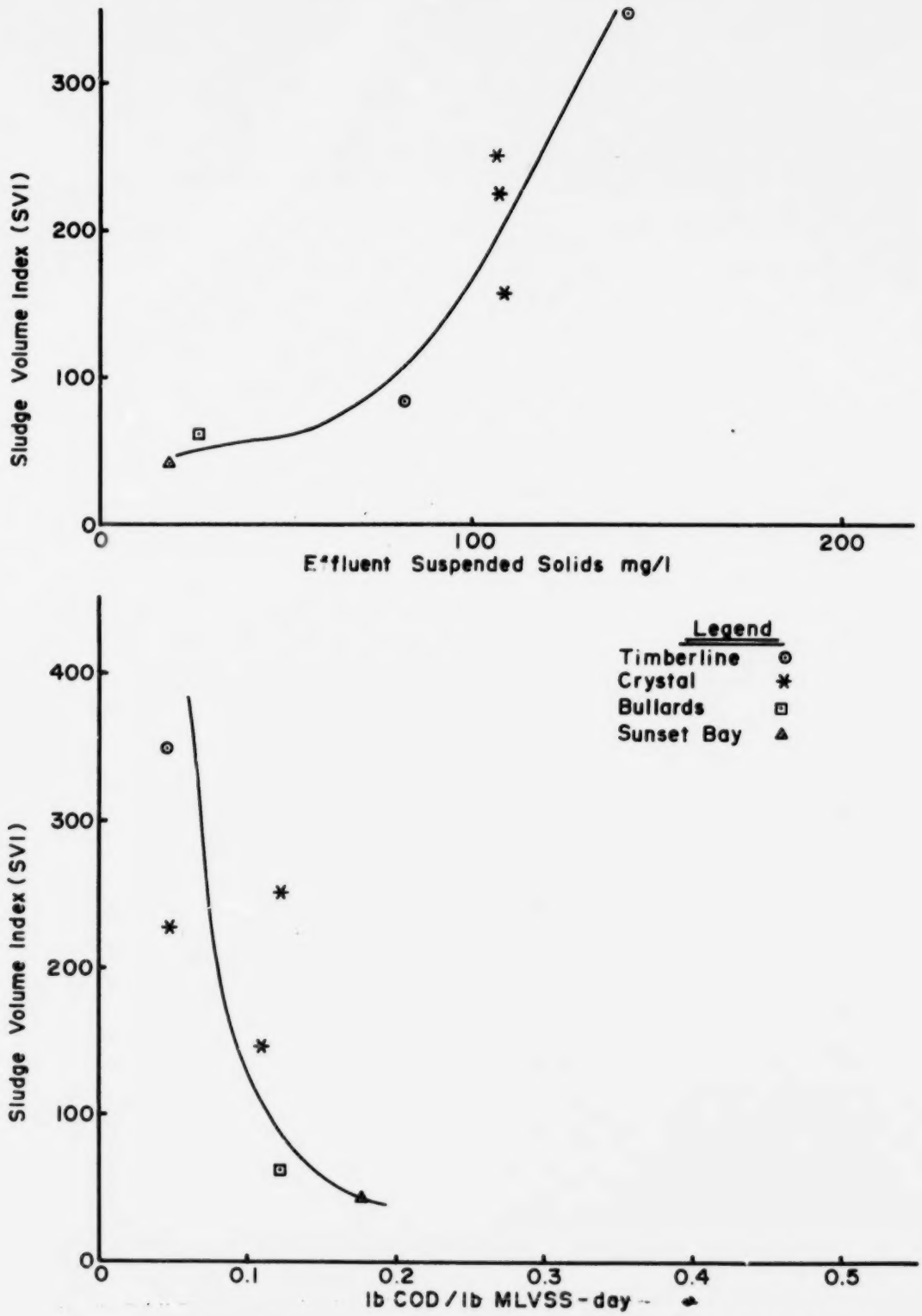

FIGURE 7. SLUDGE VOLUME INDEX (SVI) VS LOADING AND EFFLUENT SS

TABLE 8

RATIO OF BOD_5/VSS AND COD/VSS FOR THE CRYSTAL MOUNTAIN MLVSS DURING SURVEYS OF 2/10-19 and 4/26-29

Date	BOD_5/VSS	COD/VSS
2/10	0.59	1.28
11	0.49	1.08
12	0.51	1.27
13	0.48	1.16
14	0.48	1.30
15	0.42	1.02
16	-	1.51
17	0.65	1.53
18	0.60	1.10
19	0.63	1.28
Average (2/10-19)	0.54	1.25
4/26	0.36	1.38
27	0.25	1.42
28	0.31	1.20
29	0.26	1.21
Average (4/26-29)	0.30	1.30

0.2-0.3 at the high sludge ages encountered, was considerably greater than this during the first period, but agrees fairly well during the second period.

The higher ratio during the earlier survey may be attributed to nitrification in the BOD_5 analysis and the fact that the system had been operating only for 3-4 weeks prior to the survey and perhaps only 5-10 days at a significant loading level. This would indicate, then, a true sludge age considerably lower than the 122 days calculated on the basis of lb solids under aeration/lb solids wasted/day.

Alkalinity and pH

Figure 8 illustrates the variation with day of week in influent and effluent alkalinity and pH for each of the four plants studied.

At both Timberline Lodge and Crystal Mountain, there was considerable variation in the influent alkalinity and pH. On weekdays the alkalinity dropped to approximately 1/2 to 1/3 the weekend value and the pH dropped accordingly.

In the effluent, the Timberline system showed an average decrease in alkalinity of 153 mg/l or approximately 81 percent. There was a corresponding decrease in average pH from 6.7 to 5.2 with a value as low as 3.9 in the final effluent. The Crystal Mountain system had an average decrease in alkalinity of 215 mg/l or over 82 percent. The average decrease in pH through the system was not as severe as at Timberline being from 6.7 to

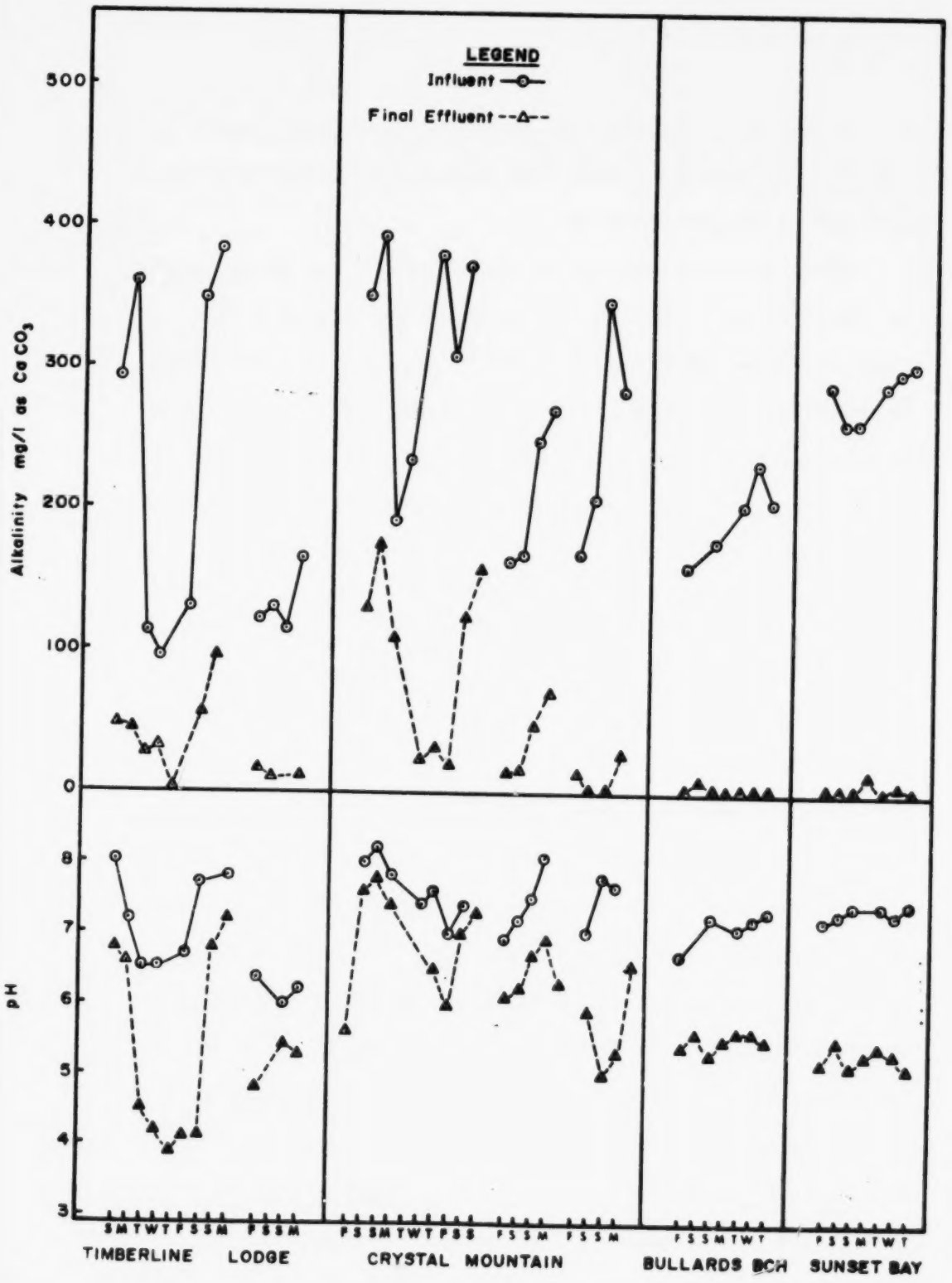

FIGURE 8. ALKALINITY AND pH VARIATIONS

6.3. The low pH value at Crystal was 5.0 which occurred during the third survey.

At Bullards Beach and Sunset Bay, the influent alkalinity and pH increased approximately 50 mg/l for alkalinity and 0.5 pH units. As shown by Figure 6, the alkalinity in the effluent was less than 10 mg/l for all days except one when it increased to approximately 30 mg/l. For Bullards Beach, this represents an average decrease in alkalinity of 192 mg/l or over 98 percent, and for Sunset Bay a decrease of 278 mg/l or nearly 99 percent. As could be expected with this large decrease in alkalinity, the average pH decreased significantly in the effluent from 7.1 to 5.4 for Bullards Beach and 7.3 to 5.3 for Sunset Bay. It is of interest to note that for Sunset Bay the major reduction in pH occurred in the final clarifier rather than in the aeration basin as was the case for the other units studied.

Aeration Sludge Analysis

During the first surveys at Timberline Lodge (January 21-29) and Crystal Mountain (February 11-19), the activated sludge in the aeration basins was subjected to a qualitative microscopic analysis.

At Timberline Lodge, the analysis indicated a protozoan population with free swimming ciliates, and a few stalked ciliates. There were very few rotifers identified, a large number of filamentous fungi and a few green algae. The floc was described as being highly dispersed.

At Crystal Mountain, there was a good protozoan population primarily of stalked ciliates. No free swimming ciliates or rotifers were found. There was a considerable amount of fungi present which was identified as Geotrichum condidum. The floc was described as being highly dispersed.

Nitrification

Figure 9 illustrates the percent nitrification, measured as quantity of (NO_3 + NO_2) in the effluent divided by quantity of total nitrogen in the influent, versus organic loading (lb BOD_5/lb MLVSS-day) for the four plants studied. This figure also illustrates a normal curve at approximately 20°C as reported by Eckenfelder[3]. Nitrification at all four plants is less than 20 percent at a loading of 0.10 lb BOD_5/lb MLVSS-day. Compared to essentially 100 percent, nitrification under normal pH and temperature conditions at this loading, it can be noted that nitrification at the areas studied is depressed considerably.

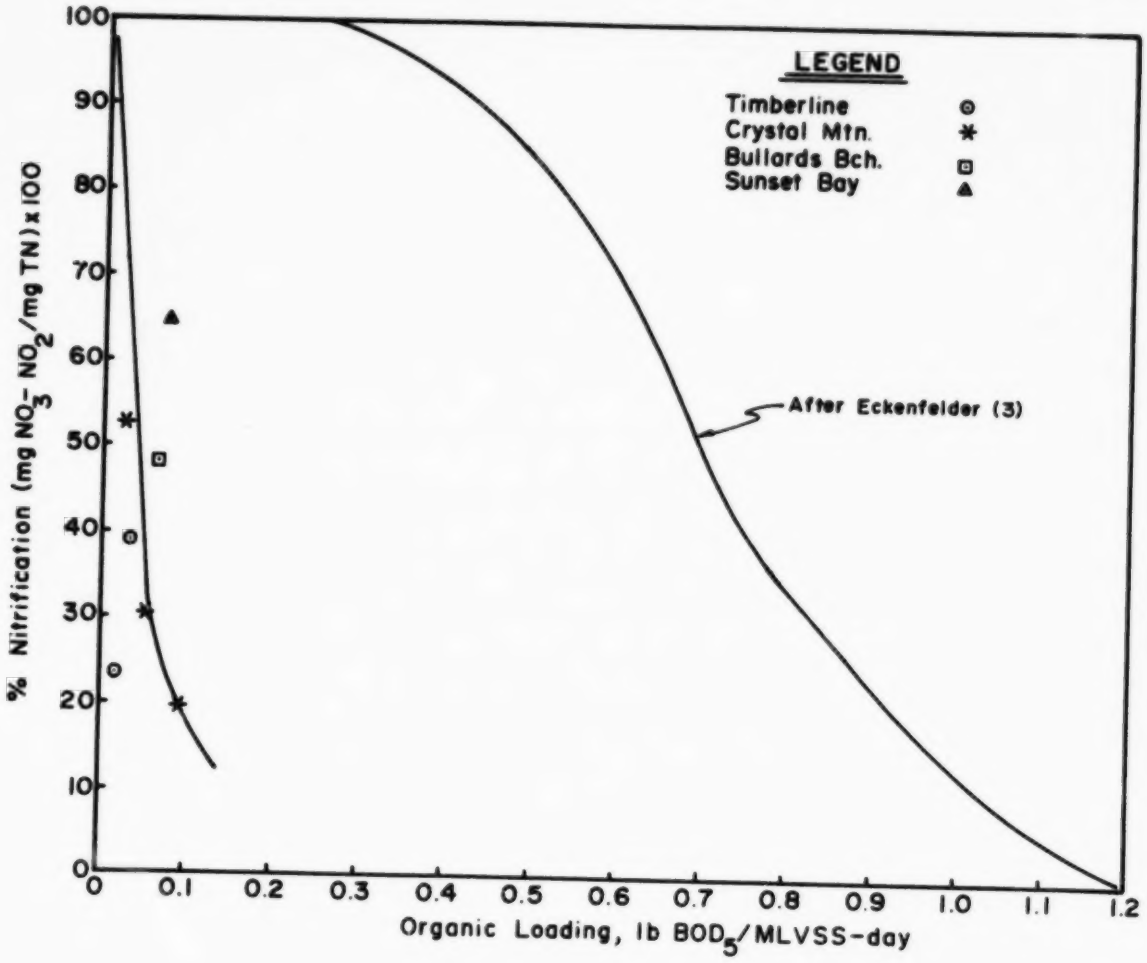

FIGURE 9. ORGANIC LOADING vs % NITRIFICATION

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DISCUSSION

This section of the report will first discuss organic removal kinetics, biological synthesis and respiration rates, nitrification and denitrification, loading effects and how these relationships apply to the systems studied.

System Organics Removal

The total efficiency of a treatment system in removing organic matter expressed as COD or BOD_5 must consider two forms of organic matter in the effluent: (1) the soluble portion, and (2) the portion contributed by organic solids which from an activated sludge process would be principally biological cells.

In terms of COD, the total removal efficiency can be expressed by the relationship:

$$E = \frac{L_o - L_E}{L_o} \times 100$$

where E = total COD removal efficiency

L_o' = total influent COD

L_E = total effluent COD

$= L_e' + L_s$

where L_e' = soluble effluent COD

L_s = effluent COD due to solids

Soluble COD

The rate of soluble COD removal in a biological treatment system is related to the quantity of active microorganisms present,

the length of time the organisms are in contact with the food source and the quantity of COD present[4]. This concept can be expressed mathematically as:

$$\frac{dL}{dt} = KS_aL \qquad (1)$$

where $\frac{dL}{dt}$ = rate of change of COD with time

K' = COD removal rate, time^{-1}

S_a = average concentration of active micro-organisms under aeration as measured by volatile suspended solids, mass/volume

L = COD remaining in reactor, mass/volume

By making a material balance around a completely mixed biological treatment system, the following relationship can be developed[3,4,16]:

$$\frac{L_o' - L_o'}{S_at} = K'L_e' \text{ or } M' = K'L_e' \qquad (2)$$

M' = $L_o' - L_e'/S_at$, Time^{-1}

L_o' = influent organic matter, mass/volume

L_e' = soluble effluent organic matter, mass/volume

t = aeration detention time,

Equation 2 passes through the origin which indicates that when $L_e' = 0$, $M' = 0$ or vice versa. However, this is seldom the case because of the organic matter that is associated with SS and a portion which is nonbiodegradable. Therefore, equation 2 is normally seen as $M' = K'L_e' \pm Z$ (3)

where Z is the combination of positive removal due to SS settling out or negative removal due to nondegradable organic matter.

Equation 3 is of the form, y = ax-b which plots as a straight line on cartesian coordinates with a slope equal to (a) and intercept equal to (b). Therefore, by plotting M' versus L_e' on cartesian coordinates, a straight line should result with a slope equal to the substrate removal rate (K') and an intercept equal to ~~Z~~. However, since (K') is temperature dependent and all data obtained in these surveys are at different temperatures, they should be adjusted before they can be compared on an equal basis. This can be done using the van't Hoff Arrhenious temperature relationship:

$$K_T = K_{20}\Theta^{T-20} \qquad (4)$$

where K_T = reaction rate at temperature T

K_{20} = reaction, rate at 20°C

T = temperature

Θ = temperature coefficient

Values have been reported for Θ in the literature ranging from 1.0 to 1.08[3,4,5,6] depending on the type of treatment system being used. A typical value for activated sludge treatment of domestic waste is 1.038 as reported by Pohl[6] and will be used in this report.

Figure 10 represents lb COD removed per lb MLVSS-day, M', converted to 20°C, for the data obtained from the four plants studied in this report, data for properly buffered activated sludge systems obtained in two surveys of the Camp Angell Job Corps Center plant during August 1967 and January 1968, and data from Pomona, California, reported by Jenkins and Garrison[7]. It will be noted that two separate curves can be drawn for these data.

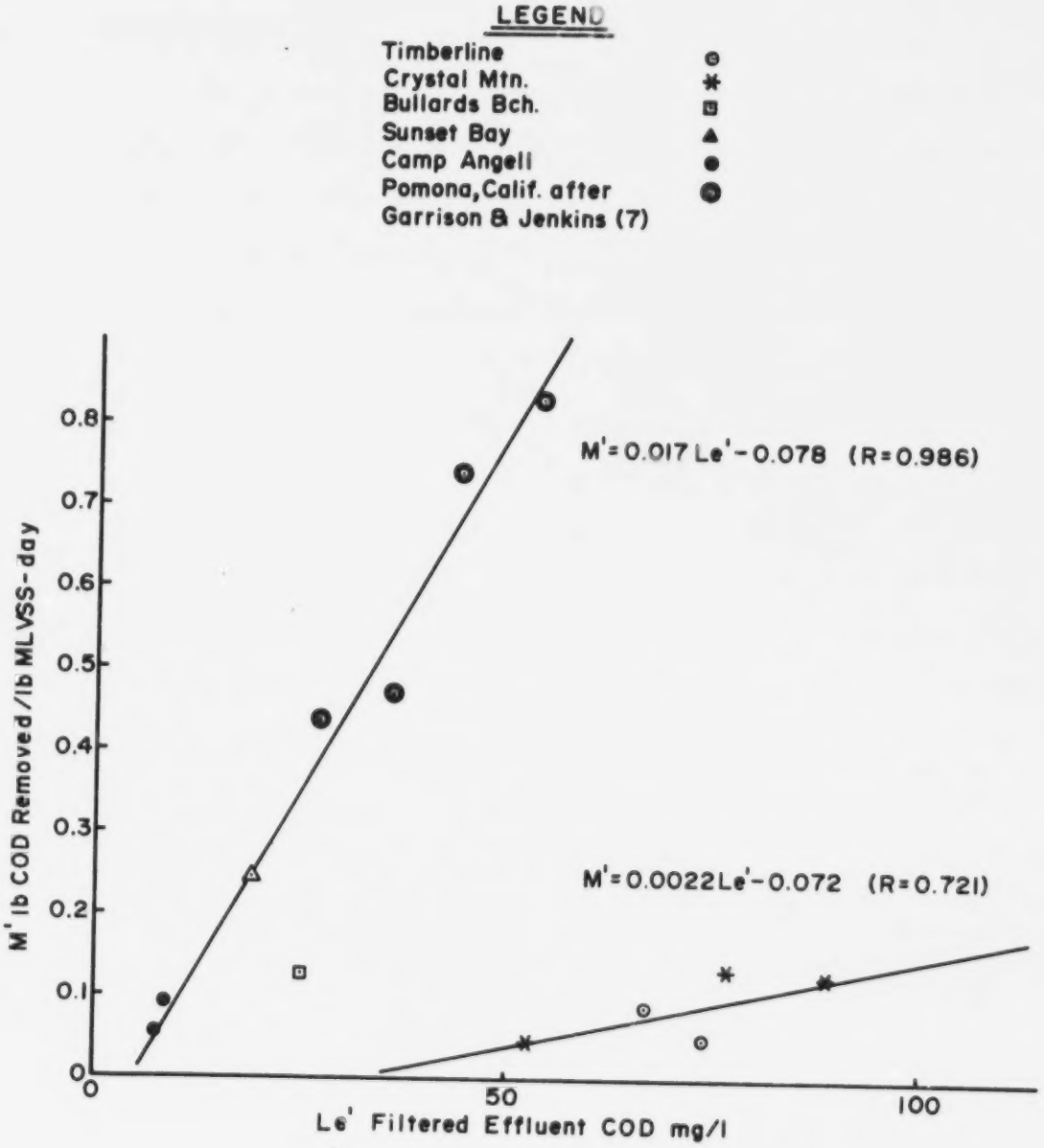

FIGURE 10. FILTERED EFFLUENT COD vs COD REMOVAL RATE

Linear regression analysis of the data indicate a 20°C COD removal rate of 0.017/day for the plants at Sunset Bay, Pomona, California, and Camp Angell, and 0.0022/day for the Timberline Lodge, Crystal Mountain, and Bullards Beach plants. The correlation coefficients of 0.986 and 0.721 for the two curves, respectively, appear to verify the linear model used to describe the reaction rate kinetics. It will be noted that the curves have a negative intercept which can be interpreted to mean that there is a portion of the substrate that is nonremovable regardless of loading level. This is not unusual when using COD as a measure of organic substrate because there is normally a portion of the COD which is nonbiodegradable and, therefore, not removable in a biological system. If the intercept were positive, this would indicate significant contribution of COD due to SS.

To investigate whether or not the removal rate was temperature dependent as previously assumed, regression analyses were performed on the Timberline, Crystal, and Bullards data before and after temperature adjustments. The correlation coefficient was improved from 0.674 to 0.721 which, although not a major improvement, still appears to confirm the temperature dependency of the removal rate coefficient.

The removal rate of 0.017/day for the Camp Angell, Pomona, and Sunset Bay data when converted to a BOD_5 basis is quite comparable to data reported in the literature that range from 0.02 to 0.04/day.

On the other hand, the rate of 0.0022/day obtained from the Timberline, Crystal, and Bullards data is extremely low and is attributed principally to low and variable aeration pH and the fact that the raw waste is unsettled prior to treatment[3,10,11]. Of these factors, variable aeration pH is perhaps the most significant, particularly at the lower temperatures encountered at Crystal and Timberline.

Eckenfelder[10] reports that a rapid change in pH will decrease the respiratory activity of biological organisms by as much as 75 percent; and this effect is compounded at low temperatures. While low pH in the aeration basins will reduce the organic removal rate significantly for a normal bacterial population, a fungi dominated population will develop that operates quite efficiently at pH levels as low as 2.5[14]. Therefore, if the pH level does drop, but remains steady, little loss in organic removal efficiency should be noted when the system reaches steady state conditions. This was indicated by the data obtained at Sunset Bay, which operated at a low, but rather steady pH level of 5.1 to 5.5, and had a normal organic removal rate comparable to those reported in the literature.

The second factor that would tend to reduce the removal rate is the fact that the waste at Timberline, Crystal, and Bullards is unsettled with approximately 30 percent of the total organic load in the form of suspended solids. It is reasoned that the portion of organic matter in the form of solids would be degraded at a lower rate than the soluble portions. Since most of the values

reported in the literature are for settled or principally soluble substrates, it seems reasonable to expect a rate somewhat lower for systems without primary settling. As mentioned before, though, this is not considered a major factor.

That portion of the effluent COD due to solids, L_s, can be expressed by the relationship XS_e, where X is the ratio of COD to VSS and S_e is effluent VSS. In terms of COD, the ratio X should be relatively constant for a given substrate with a theoretical value of 1.42 for a pure biological solid. However, there is usually a portion of nondegradable VSS in the aeration basin which lowers the ratio. In surveys at Crystal Mountain, this ratio varied from 1.25 to 1.30.

Sludge Synthesis and Endogenous Respiration

Since the quantity of new cells produced must eventually be disposed either in the effluent or through separate wasting, it is extremely important to have an estimate of the actual quantity produced in order to design sludge wasting and holding facilities. This is also important from an economic standpoint because in many installations sludge handling and disposal facilities may amount to as much as 50 percent or more of the total plant costs (capital plus operation and maintenance).

Incoming organic material, expressed as COD or BOD_5, is utilized by the microbiological population in a biological treatment system for new cell-growth and metabolic energy. This can be expressed as:

Organic Matter + bacteria + O_2 + new bacterial cells + Stable end products (CO_2, NO_3, H_2O)

It can be further expressed by the following relationship if a materials balance is made around a biological reactor at steady state conditions,

$$1/T' = aM - b(\Theta^{T-20}) \qquad (5)$$

where T' = Sludge age or lb MLVSS/lb VSS wasted per day

a = Fraction of COD or BOD_5 removed to produce new VSS or lb VSS produced/lb COD or BOD_5 removed per day

Θ^{T-20} = Temperature correction factor equal to 1.038^{T-20}

T = Temperature, °C

b = Fraction of VSS destroyed through self-respiration or endogenous respiration, lb VSS destroyed/lb MLVSS per day

Monod[5] has defined the growth rate (a) of pure cultures of microorganisms on defined substrates to be related to the concentration of a growth limiting substrate. However, it has been shown[6,7,8] that a first order approximation of the Monod equation[15], i.e., where the sludge growth rate is directly proportional to substrate concentration, can be used to estimate the growth rate in activated sludge treatment of domestic wastewater.

From inspection of a normal activated sludge growth curve, as shown in Figure 11, it can be seen that the endogenous decay rate can be described by an exponential function of sludge age

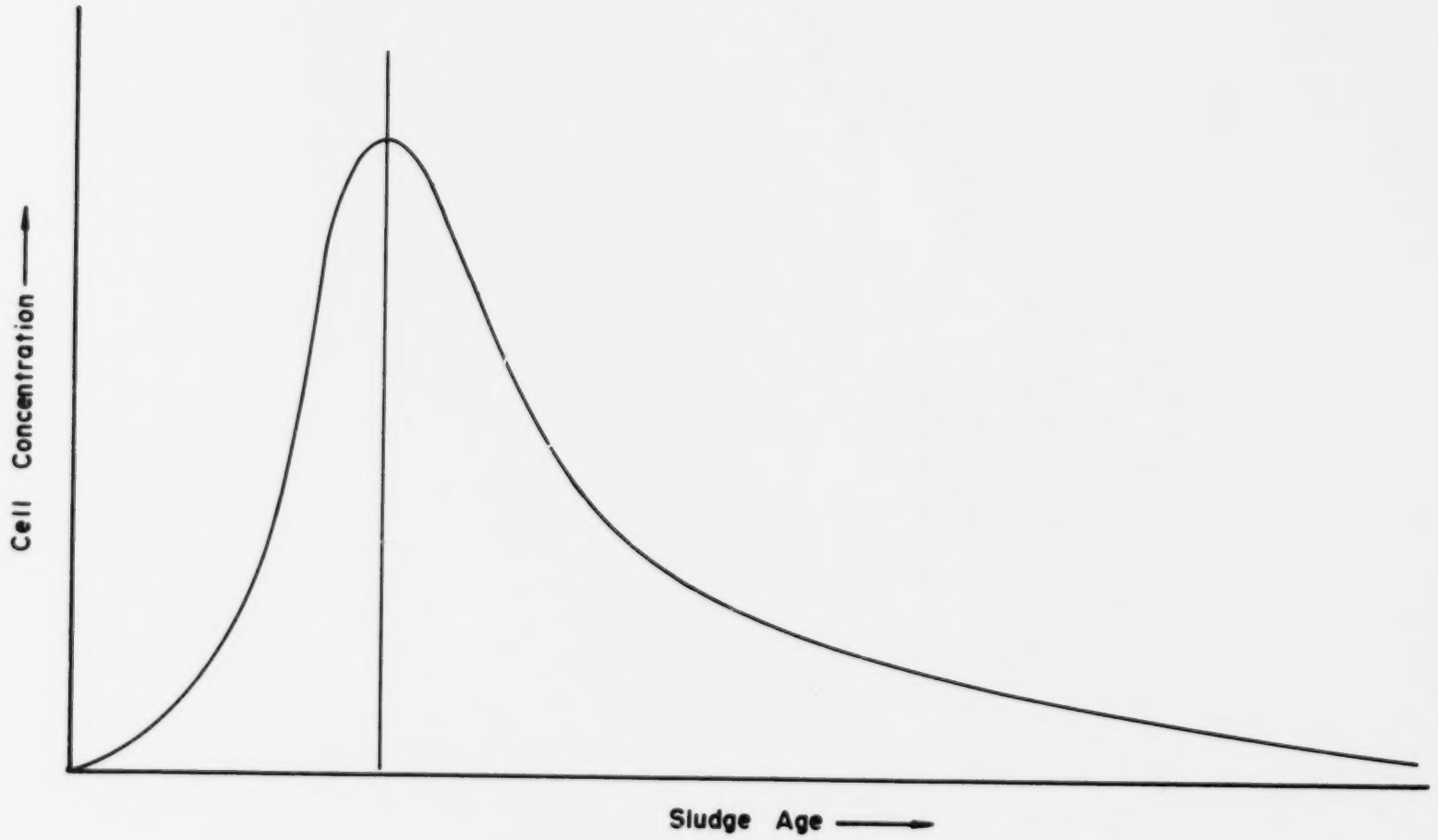

FIGURE 11. SLUDGE GROWTH CURVE

or that

$$\frac{db}{dT} = -\Phi b \qquad (7)$$

which can be reduced to the form

$$b_T = b_{max} e^{-\Phi T} \qquad (8)$$

where b_T = endogenous rate at sludge age T, days

b_{max} = maximum endogenous rate

Φ = rate die-off constant

by integration from the limts b = 0 at T = ∞ and b = b_{max} at T = 0. This assumes that the endogenous rate b is a maximum at a sludge age of 0 days which is not exactly true because of the growth period of up to one day, but should be sufficiently accurate for this analysis and most applications. This is particularly so since the growth period of one day is small compared to the die-off period.

Equation 5 then can be written as

$$1/_{T'} = aM - b_{max} e^{-\Phi T'} (1.038^{T-20}) \qquad (9)$$

Equation 9 has been curve-fitted to the data obtained in surveys at the four recreation areas as well as data from Pomona, California[7] and the constants a, b_{max}, and Φ evaluated. This was done on the basis of both BOD_5 and COD.

On the basis of BOD_5 data, the sludge synthesis fraction, a, equalled 0.54, b_{max} was equal to 0.052, and Φ was equal to 0.02. The resulting equation with these constants is shown together with the survey data in Figure 12. It can be seen that the relationship describes the data quite well.

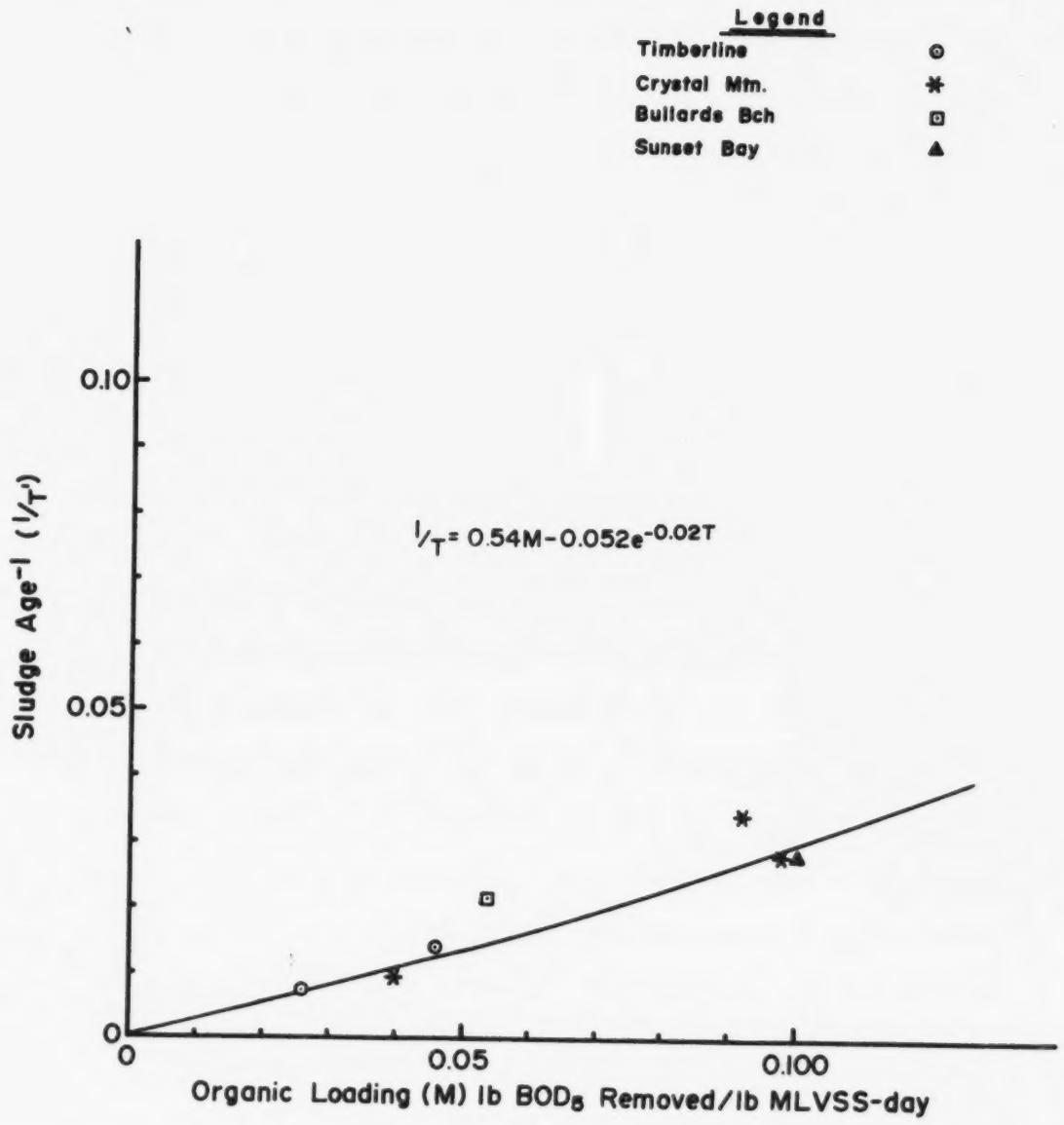

FIGURE 12. SLUDGE AGE VS BOD_5 ORGANIC LOADING

On the basis of COD data, including Pomona, California data, the sludge synthesis fraction was equal to 0.33, and both b_{max} and Φ were the same as for the BOD_5 relationship. The resulting equation and the data are illustrated in Figure 13 and again, it can be seen that there is good agreement between actual data and predicted data.

The sludge synthesis fraction, a, on the basis of BOD_5 data agrees quite well with values reported in the literature. Both the National Sanitation Foundation[17] and McCarty and Broderson[18] reported values of 0.53. The value of 0.33 calculated on the basis of COD data also agrees quite well with the value reported by Jenkins[7] and on the basis of BOD_5/COD relationship of approximately 0.58 (See Table 9, appendix) appears reasonable. The maximum endogenous rate (b_{max}) of 0.052 is quite low compared to the value of 0.18 used by Eckenfelder[11], National Science Foundation[17] and McCarty and Broderson[18], but agrees closely with the value reported by Jenkins[7] of 0.04. Since most of the work supporting the higher value of 0.13 was done on a laboratory bench scale basis, perhaps the difference between the two values is due to scale effects from the laboratory to the field. At any rate, it is felt that the values reported here and by Jenkins[7] are more reliable since they are based on actual full scale systems

While the predicted relationship between sludge age and organic removal rate given by equation 9 appears to describe the actual process satisfactorily, it should be noted that the equation

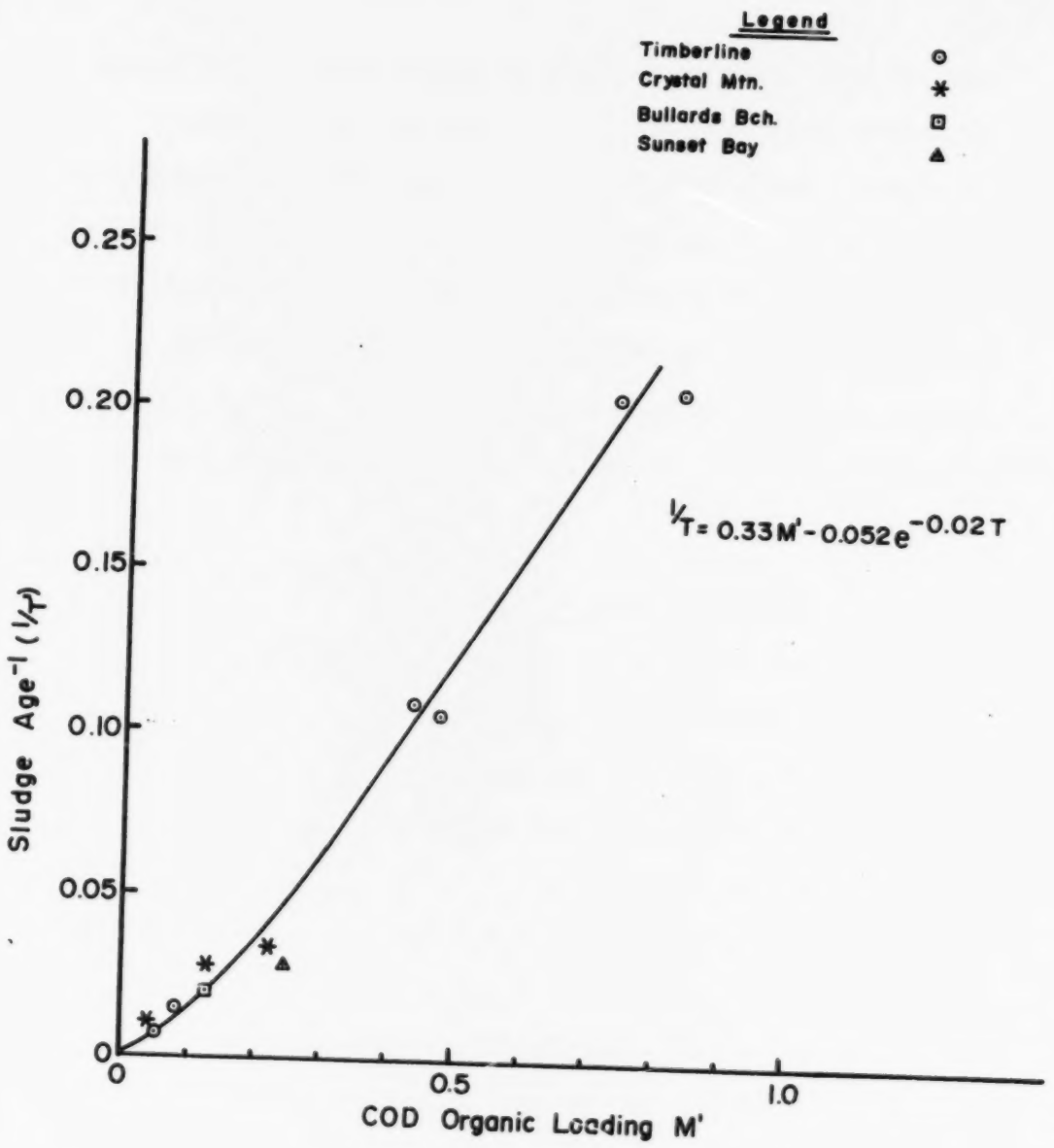

FIGURE 13. SLUDGE AGE VS COD ORGANIC LOADING

does not distinguish any possible pH effects from extended sludge age effects on the endogenous rate. However, it is felt that the equation should be satisfactory in most instances of recreation waste treatment for the reason that low variable pH appears to be a characteristic of systems that are loaded below an average of 0.10 lb COD/lb MLVSS-day and have extreme loading variations from day to day. Therefore, the extended sludge age, which generally in a completely mixed system, also means low loadings and low pH appear to be related.

Nitrification - Denitrification

This aspect of the operation of an extended aeration biological treatment system is extremely important in the control of the efficiency of the system. Nitrification can have a significant effect on pH which in turn affect the organic removal rate and solids removal efficiency. In a study of 14 small, extended aeration systems in Massachusetts, the Massachusetts Public Health Department[20/] concluded that nitrification will cause a decrease in pH in soft water areas and create an environment favorable for filamentous microorganisms. Findings from this study support essentially the same conclusion.

The oxidation of organic nitrogen to NO_3^- requires stoichiometrically one mole of alkalinity per mole of organic nitrogen converted. This

is shown by the following set of reactions:

$$\text{Org N} + \text{bacteria} \rightarrow NH_3$$

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

$$OH^- + CO_2 \rightleftharpoons HCO_3^-$$

$$NH_4^- + 2O_2 \rightleftharpoons 2H^+ + NO_3^- + H_2O$$

$$2H^+ + 2HCO_3^- \rightleftharpoons H_2CO_3$$

$$H_2CO_3 \rightleftharpoons CO_2 + H_2O$$

Adding these reactions together gives the following net reaction

$$\text{Org N} + HCO_3^- + 2O_2 \rightarrow NO_3^- + H_2O$$

Stated another way, the oxidation of 1 lb of Org N as N requires 3.6 lb of alkalinity as $CaCO_3$.

The oxidation of NH_4^+, which in normal domestic sewage accounts for approximately 90% of the organic nitrogen due to the conversion in the sewer from organic nitrogen to NH_4^+ is given by the net reaction,

$$NH_4^+ + 2O_2 + HCO_3^- \rightarrow 3H_2O + NO_3^- + 2CO_2$$

and requires 7.2 lb of alkalinity as $CaCO_3$ per lb NH_4^+ as N oxidized.

The essential difference between the two reactions is that in the first reaction one mole of alkalinity is produced in the oxidation of Org N to NH_4^+, thereby, decreasing the net requirement from one mole to two moles. In the second reaction, the same thing occurs, but the mole of alkalinity produced is measured as part of the influent alkalinity and the net requirement remains as two moles.

It should be noted, however, that these reactions are an oversimplification of an extremely complex biochemical reaction, and may not yield the 2 to 1 or 1 to 1 molar ratios shown above. On the basis of an average of the survey data obtained from all four plants, approximately 7.5 lb of alkalinity was required per lb of $NO_2 + NO_3$ produced which is close to the maximum value of 7.2 lb for NH_4^+ ion oxidation and the biochemical simplification made above may be sufficiently accurate for most purposes.

The nitrification reaction has been reported to be a function of sludge age, organic loading, dissolved oxygen, temperature and pH.

Each of these parameters are discussed with possible methods for controlling nitrification where soft waters and associated pH problems may occur.

Regarding sludge age, Eckenfelder[3] reports that the sludge age or organism retention time must be greater than their growth rate or they will be washed from the system. Generally, sludge ages on the order of 5 days or greater are necessary for nitrification. In extended aeration systems, the sludge age nearly always exceeds five days and this is not a parameter which can be controlled if it is desired to limit nitrification.

On the basis of organic loading, normally nitrification will start at a value of approximately 1.0 lb BOD/ lb MLSS at 20°C in clarified sewage with essentially complete nitrification at organic loadings of 0.2-0.3 lb BOD_5/lb MLSS. This is illustrated by Figure 9.

Regarding pH, it has been reported[12] that the optimum pH range is 7.5-8.5 with a decrease in pH causing a decrease in nitrification. This may be one reason why the percent nitrification was low in the systems studied.

Temperature is also an important variable affecting the percent nitrification. The dependence of the growth rate of Nitrosomonas sp. has been described by Downing[19] to vary according to the empirical relationship.

$$M_T = M_{15} \cdot 1.23^{(T-15)} \qquad (7)$$

where

M_{15} = growth rate of Nitrosomonas sp. at 15°C

M_T = growth rate of Nitrosomonas sp. at T°C

T = Temperature, °C

which indicates that a temperature change from 20°C to 10°C would reduce the growth rate by a factor of approximately 3 and since the percent nitrification would follow the growth rate of the organisms, this would also be reduced by a factor of three.

A point that is noteworthy, particularly in regard to the considerable effect of nitrification on pH and general system efficiency is the high concentration of organic nitrogen in the raw wastewater of the recreation areas studied. In general, the concentration was nearly double that which is normally expected from a domestic sewage. It can be seen, then, that a combination of high organic nitrogen with low or even normal alkalinity could

result in pH problems if a high percentage of nitrification occurs.

In addition to aeration pH problems, a high percentage of nitrification in the aeration basin of an activated sludge system may have a significant effect on the efficiency of the final clarifier due to rising or floating sludge through denitrification. Denitrification can be described by the equation

$$2\ NO_3^- \rightarrow 3O_2 + N_2 \uparrow$$

and can occur with a highly nitrified effluent in the final clarifier because the active microbes continue their respiration. If free dissolved oxygen is not available, oxygen is obtained through reduction of the nitrates producing nitrogen gas which bubbles off and floats the sludge. This sludge will not settle once it has been floated and will be carried out of the clarifier, thereby lowering the efficiency of the plant for suspended solids, BOD_5 and COD. The floating sludge noted at both Crystal and Timberline is attributed to denitrification. This problem can be controlled by reducing the sludge detention time in the clarifier. It is generally recommended that this time be on the order of four to six hours, but in practice, the sludge age can be used as a good guideline. With a low sludge age, and a high oxygen uptake rate, the time should be on the low side; say on the order of four hours. However, if the sludge age is high and the oxygen uptake rate is low, then a higher retention time can be used. This can be controlled by the rate of sludge return to the aeration basin. Long sludge retention times may have a practical application

in some situations where the loading is very low during the week and high during the weekends. It may then be possible to accumulate and store the sludge for a day prior to expected heavy loadings and then return it concurrent with the high loadings. This then would reduce the effect of the shock load. This concept of reducing shock loads has been expressed previously by Eckenfelder[21] and may, indeed, have application.

Solids Removal

As indicated by Figure 7, which gives the relationships between sludge volume index, effluent suspended solids and organic loading, the settleability of the sludge deteriorates rapidly at organic loadings below 0.1 lb COD/lb MLVSS-day. This is attributed to two main factors: dispersed poor settling floc and filamentous fungi.

It has been widely reported by Eckenfelder[3], McKinney[12] and others that at low organic loadings, a highly dispersed microbial population develops that is composed of single cells and cell fragments, which have very poor settling characteristics. Apparently, this begins to occur at the areas studied at loadings below 0.1 lb COD/lb MLVSS-day or approximately 0.05 lb BOD_5/lb MLVSS-day. The other contributing factor is filamentous fungi which begin to develop at pH levels below 6.0. Analysis of the sludge at both Crystal Mountain and Timberline indicated significant concentrations of fungi which is not surprising with the low aeration pH at these

areas. The development of the fungi can also be attributed to low loadings because of the relationship between organic loading nitrifications and reduction in alkalinity and pH. As indicated by Figure 9, significant nitrification began to occur at organic loadings below 0.1 lb BOD_5/lb MLVSS-day.

Other factors that will effect the solids removal efficiency is the hydraulic loading on the clarifier in terms of surface loading (gpd/ft^2) and the sludge detention time. If the surface loading, which can also be equated to sludge rise velocity, exceeds the settling velocity of the sludge, then the sludge will be carried out of the system. At the four systems studied, the average surface loadings were well below those values normally used in design of activated sludge systems. However, when considering the peak flow rates, the surface loadings were excessive, and in all probability, contributed significantly to the solids carryover.

The sludge detention time is a factor because if it is too long, the clarifier will tend to go anaerobic in the inner layers of the sludge blanket, creating conditions for denitrification and floating sludge. Since floating sludge was noted on several occasions at both Timberline Lodge and Crystal Mountain, it is surmised that both systems had long hydraulic detention times in the clarifiers that allowed the development of anaerobic conditions. The sludge return rate was not measured so that no actual values can be computed for the clarifier detention times.

DESIGN CONSIDERATIONS

In the design of an extended aeration activated sludge system to treat a recreation waste, the following comments and discussion are offered for the consideration of the design engineer or the plant operator.

The organic loading should be considered, perhaps as the most important variable involved and will be highly dependent on having accurate waste flow and strength estimates. Since the minimum load level of 0.05 lb BOD_5/lb MLVSS-day is considered the critical level, the conservative design approach used by many agencies and firms in the past cannot be considered adequate. The maximum level will usually be dictated by the maximum allowable soluble BOD_5 in the effluent, but as a general rule should probably be kept below 0.5 lb BOD_5/lb MLVSS-day.

The limitations in the sludge return system and levels of MLVSS that can be maintained in the aeration basin will generally dictate the average organic loading level to be used.

If the organic loading level is maintained in the range discussed above, the sludge should not become highly dispersed, but remain flocculent and the possibility of pH problems occurring will be minimized. This is particularly true for ski areas where low temperatures will also hold down the percent nitrification. It should be noted, though, that if the raw waste has sufficient alkalinity, then in most instances, it would be better to encourage nitrification.

It is recognized that much of the material presented in this report lacks sufficient verification on which to base actual design recommendations; and consequently, much of the material is presented as information only. In the final report from the Recreation Project, results will be presented on controlled pilot plant studies that have been designed to answer many of the questions that will arise. In addition, a recommended design approach will be given that incorporates much of the information presented in this report.

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APPENDIX

TABLE 9. TIMBERLINE LODGE RAW SEWAGE

Analysis Mg/l	1/21	1/22	1/23	1/24	1/25	1/26	1/27	1/29	5/10	5/11	5/12	5/13	Ave.
BOD_t	485	540	620	460	330	460	430	388	145	198	280	345	395
BOD_c	245	340	255	225	-	215	265	205	-	-	-	-	250
COD_t	899	917	994	868	827	869	536	659	286	533	710	790	749
COD_c	540	-	-	377	459	320	296	-	-	-	-	-	398
TS	853	-	620	570	-	1000	-	-	350	432	570	860	657
TVS	586	-	474	414	-	730	-	-	196	180	448	384	426
SS	420	-	480	380	-	600	-	-	92	156	244	192	321
TVSS	390	-	400	300	-	540	-	-	80	130	212	172	278
Lab pH	8	7.2	6.5	6.5	-	6.7	7.7	7.8	6.4	-	6.0	6.2	6.8
Alk	294	360	112	96	-	131	349	384	122	130	115	165	205
Field pH	7.3	6.7	6.0	6.0	-	6.2	7.1	7.2	5.6	5.5	5.7	5.8	6.2
TPO_4	12.6	14.5	12.4	9.8	-	16.5	14.1	12.5	9.5	14.9	9.7	-	12.7
OPO_4	6.8	7.4	6.7	4.7	-	6.9	6.6	7.6	4.4	7.7	3.6	-	6.2
NH_3	-	-	-	-	-	22.7	5.9	102	8.0	16.9	15.9	-	28.5
NO_3	-	-	0.12	0.2	0.27	0.08	0.49	0.07	0.08	0.59	0.12	-	.22
NO_2	-	-	0.06	0.08	0.21	0.08	0.11	0.03	0.05	0.08	0.08	-	.09
KN	89.2	112.7	49.3	44.6	57.6	49.3	105.3	203.0	44.0	56.0	32.4	-	76.6
Cl	-	-	-	-	-	-	-	-	23	13	14	140	48
TH	26	36	36	27	-	24	29	35	21	40	23	29	30
CaH	22	30	31	22	-	23	19	26	20	37	1	25	23

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TABLE 9. TIMBERLINE LODGE RAW SEWAGE (Continued)

Analysis Mg/l	1/21	1/22	1/23	1/24	1/25	1/26	1/27	1/29	5/10	5/11	5/12	5/13	Ave.
Hours in Composite	24	24	24	12	12	24	24	7	24	C/T[a/]	C/T	C/T	19
Flow gpd	12,400	10,400	6,000	4,800	9,800	5,200	9,200	12,000	3,800	5,700	15,800	5,200	8,358

a/ C/T = Composited with time

TABLE 10

TIMBERLINE LODGE AERATION

Date	Analysis SS mg/l	Analysis TVSS mg/l	Lab pH	Field pH	ALK mg/l
1/20	1375	1250	-		32
1/21	2300	2030	-		73
1/22	1720	1520	-		65
1/23	1280	1080	-		26
1/24	1740	1520	-		32
1/25	2330	2030	-		2
1/26	2620	2280	-		58
1/27	2320	2040	-		126
1/28	2300	2000	-		150
1/29	2760	2440	-		112
3/22	1888	1641	6.7	4.2	200
3/23	-	-	-	6.3	-
3/24	2480	2156	6.8	5.8	90
3/25	1620	1416	7.1	5.1	73
3/26	1292	984	6.6	5.1	56
5/10	2300	2100	5.2	4.0	93
5/11	2250	2100	-	4.2	86
5/12	1900	1780	5.6	4.6	79
5/13	1650	1480	6.3	4.6	60

TABLE 11

TIMBERLINE LODGE CLARIFIED

Analysis Mg/l	1/20	1/21	1/22	1/23	1/24	1/25	1/26	1/27	1/28	1/29	3/22	3/23	3/24	3/25	3/26	5/10	5/11	5/12	5/13
BOD_t	-	220	35	43	34	45	15	25	51	79	90	83	138	80	73	44	32	78	34
BOD_c	-	-	18	16.5	12	6	4	9	9	9	8	11	11	9	8	8.5	6	7	9
COD	538	576	586	106	90	287	67	90	148	182	370	257	305	210	288	128	193	260	105
COD_c		51a/	66b/	63	64a/		51a/	58a/	87a/	98a/	102					71	78	67	80
TS	-	791	-	-	416	404	380	382	410	370	-	-	-	-	-	-	-	-	-
TVS	-	534	-	-	238	194	174	194	218	174	-	-	-	-	-	-	-	-	-
SS	-	440	-	-	32	-	24	32	64	140	120	13	172	56	48	76	168c/	281c/	44
TVSS	-	400	-	-	20	-	12	24	48	64	107	20	156	60	36	64	151a/	253a/	36
pH	-	6.8	6.6	4.5	4.2	3.9	4.1	4.1	6.8	7.2	7.0	-	4.9	5.7	6.9	4.8	-	5.4	5.3
Alk	-	47	44	-	-	-	-	-	56	97	54	-	3	6	27	17	11	-	11
TPO_4	-	13.92	9.07	9.69	9.80	9.69	10.78	9.69	9.80	9.30	10.60	9.00	11.20	10.10	11.10	9.40	11.70	9.70	-
OPO_4	-	7.40	7.53	7.31	6.48	6.89	6.68	5.89	6.84	6.84	8.10	8.20	8.00	7.00	6.40	6.90	5.70	8.00	-
NH_3	-	-	7.56	12.80	9.70	5.60	6.30	6.60	19.80	31.50	7.40	6.70	15.70	15.50	9.80	<.10	4.50	4.30	-
NO_3	24.28	22.82	32.28	31.50	30.80	30.30	33.20	27.40	21.40	20.80	15.70	1.40	5.97	4.47	6.79	1.13	13.30	10.90	-
NO_2	.84	.17	.25	1.14	<.01	<.01	<.01	<.01	<.01	.49	1.67	.75	1.05	4.69	8.67	.08	.40	4.87	-
KN	44.6	45.5	56.4	14.0	10.2	24.3	8.8	3.1	27.1	34.7	21.3	21.7	29.6	27.9	24.0	10.5	16.1	20.1	-
TH	-	27	26	39	49	42	40	54	22	22	-	-	-	-	-	-	-	-	-
CaH	-	22	22	29	32	26	32	28	21	18	-	-	-	-	-	-	-	-	-

a/ - Estimated on basis of 1.31 mg COD/mg VSS
b/ - Estimated on basis of BOD_5 = 0.42 COD-10 (mg/l)
c/ - Estimated on basis of 0.90 VSS/SS

TABLE 12

CRYSTAL MOUNTAIN RAW SEWAGE

(All values in mg/l except pH, Color, and Flow)

Analysis	2/10	2/11	2/12	2/13	2/14	2/16	2/17	2/18	2/19	3/8	3/9	3/10	3/11	4/26	4/27	4/28	4/29
BOD	-	335	350	188	255	416	500	640	520	230	200	330	150	183	198	450	740
COD	-	1081	1314	514	652	833	838	1380	1002	500	380	710	290	310	337	680	1270
TS	-	736	960	740	688	740	900	1300	1090	624	420	1000	340	504	528	848	1160
TVS	-	520	608	560	500	472	612	952	800	480	290	800	172	364	328	624	896
SS	-	340	456	300	310	360	450	860	168	260	136	540	192	168	296	340	780
VSS	-	300	408	280	310	312	390	780	160	196	120	490	180	164	260	340	780
Lab pH	-	8.0	8.2	7.8	-	7.4	7.6	7.0	7.4	6.9	7.2	7.5	8.1	6.7	7	7.8	7.7
Alkalinity	-	350	392	191	235	378	334	307	370	162	167	248	270	167	208	347	283
TPO_4 as P	-	11.4	11.8	8.1	20.7	14.4	19.5	28.9	18.2	6.4	4.5	14.1	6.6	5.1	9.5	13.5	17.3
OPO_4	-	7.6	7.2	5.8	5.9	9.0	12.1	11.3	10.6	3.8	3.1	5.8	4.3	3.5	6.5	8.8	11.6
NH_3 as N	-	11.5	14.5	59.4	-	-	-	-	31.4	8.7	8.9	13.7	14.1	8.2	14.6	15.5	23.4
NO_3 as N	-	0.33	0.29	0.35	0.36	-	0.29	0.37	<0.05	0.1	0.1	0.07	0.11	0.2	0.32	0.3	0.07
NO_2 as N	-	0.07	0.09	0.09	0.03	-	0.05	0.04	0.04	0.05	0.11	0.12	0.04	0.06	0.1	0.13	0.21
TKN as N	-	112	103	60.0	72	-	83	94	114.4	40.5	54.1	70.3	51.3	42	59	126	118

TABLE 12

CRYSTAL MOUNTAIN RAW SEWAGE (Continued)

(All values in mg/l except pH, Color, and Flow)

Analysis	2/10	2/11	2/12	2/13	2/14	2/16	2/17	2/18	2/19	3/8	3/9	3/10	3/11	4/26	4/27	4/28	4/29
Color	-	100	60	75	-	75	100	-	150	75	40	300	100	175	100	200	400
Hours in Composite	-	19	24	20	17	19	23	22	21	20	20	20	24	19	20	24	19
Flow	14,700	32,900	14,530	6,020	5,660	9,840	26,600	17,100	5,805	19,100	47.000	24,000	17,400	2,590	5,590	11,610	9,090
Field pH	-	6.3	6.1	6.6	6.7	6.5	6.7	6.2	6.4	6.9	6.7	6.7	6.8	7.0	6.6	6.7	6.9

TABLE 13

CRYSTAL MOUNTAIN AERATION

Date	(All values in mg/l except pH, and temperature, °C)												
	BOD_t	BOD_c	COD_t	COD_c	SS	TVSS	pH	ALK	NH_3	NO_3	NO_2	KN	TEMP
2/10	1295	40	2904	195	2460	2120	7.0	-	43.5	10.00	12.60	-	6
2/11	1520	24	3455	153	3640	3060	7.3	262	51.6	.05	.18	285	4.5
2/12	1700	26	4355	188	3750	3280	7.2	276	50.9	7.87	18.70	309	5
2/13	1625	13	4046	190	3830	3330	6.8	154	33.7	9.00	30.60	284	3
2/14	1625	53	4498	207	3780	3300	-	68	31.3	9.79	27.90	261	2
2/15	1600	64	3951	202	4250	3700	-	50	-	-	-	-	1
2/16	-	-	4689	309	3350	2900	7.2	186	24.6	10.40	25.30	247	1
2/17	1750	27	4427	357	2750	2650	6.9	173	31.2	8.97	22.20	202	5
2/18	2275	29	4345	198	4230	3750	7.0	225	42.3	4.83	21.10	243	5
2/19	2175	14	4609	178	3950	3450	6.9	130	19.7	3.25	22.20	-	6
3/8	-	90	4900	-	3640	3170	6.5	129	13.4	12.50	8.24	117	6
3/9	1650	45	4540	-	2400	2130	6.8	134	19.3	8.90	11.70	114	6
3/10	700	48	1270	-	3450	3060	7.0	176	25.4	1.05	1.64	220	6
3/11	6800	75	4600	-	4080	3590	7.1	155	25.6	1.51	1.94	249	6
3/12	1038	63	3900	-	3370	2970	6.5	71	21.4	1.98	1.20	65.4	6
4/26	1925	62	7460	320	5680	5180	6.5	-	25.5	47.70	.01	259	3.5
4/27	1118	14	6440	264	4670	4350[a/]	6.4	178	25.8	46.60	<.01	260	5.5
4/28	863	28	3420	180	2920	2700	7.0	160	29.4	41.40	.02	162	5
4/29	938	27	4480	180	3800	3560	6.9	144	24.4	44.70	.01	224	6

a/ Estimated from COD data on basis of 1.42 mg COD/mg VSS

TABLE 14

CRYSTAL MOUNTAIN EFFLUENT

All values in mg/l except pH, turb(Jackson turbidity units) and color (Cobalt units)

Analysis	2/10	2/11	2/12	2/13	2/14	2/15	2/16	2/17	2/18	2/19	3/8	3/9	3/10	3/11	3/12	4/26	4/27	4/28	4/29
BOD_t	60	66	47	150	330	318	78a/	38	56	205	65	64	97	62	62	53	59	46	46
BOD_c	24	32	18	12	9	24	17a/	17	17	16	18	18b/	45	26	26	17	-	17	20
COD_t	185	153	129	243	876	976	171	200	271	328	150	163	400	154	160	289	171	169	151
COD_c	90	97	83	88	159	133	-	90	86	89	53d/	53d/	136d/	72d/	72d/	51d/	51	51d/	58d/
TS	388	324	332	448	900	1130	476	450	580	368	284	284	240	275	530	472	516	460	404
TVS	196	172	176	228	620	820	250	280	388	184	152	145	132	120	370	264	316	256	200
SS	108	92	24	112	660	700	144	52	100	232	74	84	202	63	67	182	88	90	71
VSS	68	64	24	104	570	610	120	48	100	204	36	44	36	32c	48	56	40	48	40
pH	5.6	7.6	7.8	7.4	-	-	6.5	6.0	7.0	7.3	6.1	6.2	6.7	6.9	6.3	5.9	5.0	5.3	6.6
Alk	-	130	176	109	69	22	31	20	123	156	13	17	49	72	23	14	1	3	26
Turb	35	-	50	33	-	-	41	38	25	20	27	30	28	27	32	35	38	36	25
Color	-	75	75	75	-	-	80	60	80	40	40	40	100	75	120	75	100	100	100
TPO_4	8.85	8.40	8.20	8.70	22.10	18.30	9.40	10.40	10.30	10.20	5.60	6.30	7.20	9.10	7.10	10.30	9.60	9.90	10.10

TABLE 14

CRYSTAL MOUNTAIN EFFLUENT (CONT'D)

All values in mg/l except pH, turb(Jackson turbidity units) and color (Cobalt units)

Analysis	2/10	2/11	2/12	2/13	2/14	2/15	2/16	2/17	2/18	2/19	3/8	3/9	3/10	3/11	3/12	4/26	4/27	4/28	4/29
OPO_4	5.94	5.90	5.90	6.00	6.80	9.80	9.00	9.00	8.20	7.30	4.10	4.80	5.50	7.30	5.50	9.10	9.10	9.00	-
NH_3	16.2	44.7	56.3	46.3	23.3	-	16.1	17.0	28.9	38.0	10.7	11.6	22.4	29.5	24.6	26.6	24.5	24.5	28.5
NO_3	14.80	9.65	6.85	6.99	36.20	-	37.00	36.40	23.00	3.73	7.00	5.70	.53	.49	.68	45.60	46.30	44.90	41.30
NO_2	15.60	13.80	13.80	20.30	1.30	-	1.25	1.33	1.53	12.20	15.90	17.20	1.99	2.43	2.81	.03	.01	.04	4.15
KN	-	69.0	64.0	59.6	93.0	-	34.8	32.0	61.0	58.4	18.1	20.4	50.1	33.1	39.7	39.0	29.8	28.2	41.0
Cl	54	62	60	69	58	69	61	63	68	62	46	48	47	65	87	48	46	45	50

a/= estimated value on basis of VSS and COD_T
b/= estimated value on basis of comparison with data for 3/8
c/= estimated value on basis of average SS/VSS for 3/8, 9, 10, 12
d/= estimated value on basis of BOD_5 = 0.42 COD-10

TABLE 15 TIMBERLINE LODGE TREATMENT PLANT
FIELD DATA SHEET

Date	Influent			Aeration					CLA EFF			Air	Totalizer
	Temp. °C	pH	Time	Temp. °C	pH	% Solids	D.O.a/	Time	Temp. °C	pH	Time	Temp. °C	RDG gal
3/22/68	24.0	7.3	1130	14.2	4.2	16	27.5	1050	14.5	5.2	1140	-	52050
3/23/68	19.5	6.8	1115	13.5	6.3	0	12.5	1120	14.0	6.1	1140	-	52330
3/24/68	17.5	6.9	1135	14.5	6.0	17	6.0	1140	14.0	6.4	1150	-	52924
3/25/68	17.5	6.8	1125	13.5	5.1	15	33.5	1140	14.0	6.5	1145	-	53282
3/26/68	18.0	6.9	1130	12.5	5.1	11	55	1140	12.5	5.4	1145	-	53478
5/10/68	14.0	5.6	0900	10.5	4.0	70	73	1000	10.0	5.3	1115	9.0	71270
5/11/68	13.0	5.5	1030	10.0	4.2	75	67	0830	10.0	6.0	1200	12.0	71550
5/12/68	12.0	5.7	0930	10.0	4.6	72	63	0815	8.0	6.0	1100	4.5	72340
5/13/68	12.0	5.8	0930	10.0	4.6	63	72	1000	8.0	6.0	1105	8.0	72600

a/ % Saturation

TABLE 16. CRYSTAL MOUNTAIN
FIELD DATA SHEET (CONT.)

	Influent		Aeration				Final		
Date	Temp. °C	pH	Temp. °C	pH	% Solids	D.O.	Temp. °C	pH	Air Temp. °C
3/11/68	6.0	6.8	6.0	6.5	94	14	6.0	7.2	+1.0
3/12/68	6.0	6.7	6.0	6.6	83	23	6.0	6.9	+1.0
4/26/68	6.0	7.0	3.5	6.9	92	64	4.0	7.2	1.0
4/27/68	6.0	6.6	5.5	6.0	93	29	5.5	6.2	9.0
4/28/68	6.0	6.7	5.0	6.0	90	30	6.0	6.4	15.0
4/29/68	7.0	6.9	6.0	6.0	91	59	6.0	6.4	14.0

TABLE 16. CRYSTAL MOUNTAIN
FIELD DATA SHEET

Date	Influent		Aeration				Final		Air
	Temp. °C	pH	Temp. °C	pH	% Solids	D.O.	Temp. °C	pH	Temp. °C
2/08/68	-	-	-	-	-	-	-	-	-
2/09/68	-	-	-	-	-	-	-	-	-
2/10/68	-	-	6.0	7.3	31	32	6.0	7.1	7.0
2/11/68	6.5	6.3	4.5	6.9	42	31	6.0	6.7	0.0
2/12/68	6.0	6.1	5.0	6.5	75	34	5.5	6.8	1.0
2/13/68	8.0	6.6	3.0	6.2	45	55	6.0	6.3	-4.0
2/14/68	5.0	6.7	2.0	6.3	43	48	6.0	6.5	0.0
2/15/68	4.0	-	1.0	-	47	-	5.0	-	-7.0
2/16/68	6.0	6.5	1.0	6.2	45	40	6.0	6.4	-4.0
2/17/68	6.0	6.7	5.0	6.8	49	46	6.0	6.6	0.0
2/18/68	6.0	6.2	5.0	6.4	75	31	6.0	6.9	2.0
2/19/68	6.5	6.4	6.0	7.4	74	33	6.0	7.2	6.0
3/08/68	4.0	6.9	6.0	6.7	80	29	6.0	5.5	-4.0
3/09/68	5.0	6.7	6.0	6.6	75	21	6.0	6.5	-1.0
3/10/68	6.0	6.7	6.0	6.4	80	10	6.0	6.6	-1.0

TABLE 17. BULLARDS BEACH RAW SEWAGE
(All values in mg/l except for pH)

Analysis	6/14/68	6/15	6/16	6/17	6/18	6/19	6/20	Ave.
Temp. °C	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Flow, gpd	6957	7646	7816	8210	8065	8262	8268	7889
TS	300	536	392	--	370	396	410	400.7
TVS	--	--	--	--	--	--	--	--
SS	24	100	64	--	100	100	60	75
COD	147	225a/	140	--	193	220a/	182	185
BOD_5	50	100b	54a/	--	82	97	90	79
TOC	32	48	36	--	40	45	45	41
NH_3	30.1	37.7	37	--	42.2	48.5	38.5	39
NO_2	.017	.023	.019	--	.023	.027	.009	0.02
NO_3	<.001	<.001	<.001	--	<.001	<.001	.003	0.0013
TKN	36.4	47	43	--	51	58	42.5	46.32
TPO_4	4.13	5.30	4.60	--	5.10	7.10	5.0	5.2
OPO_4	1.43	0.88	1.47	--	2.18	3.20	2.76	--
Alk	158	--	176	--	202	233	205	195
pH	6.7	--	7.2	--	7.1	7.2	7.3	7.1
TH	105	85	77	--	66	69	63	77.5
Fe	11300	--	9.440	--	11.600	8.720	7.260	9.664

a/= Based on relationship, BOD_5 = 0.525 COD-20

TABLE 18. SUNSET BAY RAW SEWAGE
(All values in mg/l except for pH)

Analysis	6/14/68	6/15	6/16	6/17	6/18	6/19	6/20	Ave.
Temp. °C	17.0	16.0	16.0	16.0	14.0	15.0	16.0	15.7
Flow, gpd	12737	14250	12073	14573	10826	13166	12546	12881.6
TS	440	400	416	--	450	388	480	429
TVS	276	216	156	--	196	216	276	223
SS	44	156	40	--	48	28	36	59
COD	196	188	171	--	175	208	189	188
BOD_5	97	77	78	--	75	82	81	82
TOC	40	44	42[a/]	--	43	47	45	47
NH_3	67.4	59.4	59.5	--	68.3	68.5	71.7	65.8
NO_2	.021	.016	.007	--	.021	.017	.009	0.015
NO_3	.014	.013	.009	--	.004	.004	.026	0.012
TKN	80	67	79	--	72.9	72	71.5	73.73
TPO_4	8.90	7.50	8.40	--	--	--	--	--
OPO_4	6.20	5.90	6.00	--	--	--	--	--
Alk	287	260	262	--	286	297	303	282.5
pH	7.2	7.3	7.4	--	7.4	7.3	7.4	7.333
TH	78	7.6	90	--	77	63	70	75.67
Fe	1740	1090	1310	--	1160	1230	1090	1270

a/= Based on relationship of $BOD_5 = 3.28TOC-59$

TABLE 19. BULLARDS BEACH AERATION

Analysis	6/14/68	6/15	6/16	6/17	6/18	6/19	6/20	Ave.
TVS mg/l	--	--	--	--	--	--	--	--
SS mg/l	1280	900	920	1080	1200	1160a/	1120	997.1
Alk mg/l	19	19	37	19	25	90	93	43.14
pH	5.85	5.7	6.2	5.8	5.9	6.8	6.6	6.121

a/ = Estimated value

TABLE 20. SUNSET BAY AERATION

Analysis	6/14/68	6/15	6/16	6/17	6/18	6/19	6/20	Ave.
TVS mg/l	700	640	660	504	800	960	1060	760.6
SS mg/l	780	760a/	740	780	860	760	900	717.1
Alk mg/l	52	39	69	32	58	82	49	54.43
pH	6.4	6.2	6.7	6.3	6.6	6.7	6.6	6.5

a/= Estimated value

TABLE 21. BULLARDS BEACH CLARIFIER EFFLUENT

Analysis	6/14/68	6/15	6/16	6/17	6/18	6/19	6/20	Ave.
TVS	—	—	—	—	—	—	—	—
SS	28b	15b	28	20b/	48	24b/	10b/	25
COD	53	37	62	45a/	66a/	60	45	52.6
COD_C	21a/	20a/	29	22	18a/	33	33	25.2
BOD	33	18a/	36a/	24	38	34	24	31
BOD_C	8	7	13	7	6	16a/	16a/	11.8
TOC	17	16	20	18	18	18	18	17.86
NH_3	11.2	13	14	12.6	12	13.4	13	12.74
NO_2	.52	1.18	1.16	.84	1.05	1.13	1.14	1.003
NO_3	19.9	20.1	20	21.4	20.6	21.5	24.8	21.19
TKN	11.8	14.6	21.2	16.9	14.9	13.5	11.2	14.87
TPO_4	1.79	2.57	3.70	2.15	2.00	2.29	3.40	2.60
OPO_4	1.12	1.26	1.59	1.43	1.71	1.90	2.40	1.60
Alk	2	8	4	2	1	3	3	3.286
pH	5.1	5.9	5.5	5.4	4.9	5.2	5.7	5.386
Fe	5.480	5.810	6.170	2.542	5.080	4.360	2.180	4.517

a/= Estimated from relationship BOD_5 = 0.67 COD-6.5

b/= Estimated from 1.15 mg COD/mgSS

TABLE 21. SUNSET BAY CLARIFIER EFFLUENT(CONT.)

ANALYSIS	6/14/68	6/15	6/16	6/17	6/18	6/19	6/20	Ave.
TVS	168	284	196	256	264	264	740	310.3
SS	9b/	49b	40b/	3	8b/	24b/	4	20
COD	26a/	76a/	66	24	29	44	24	25.29
COD_C	16	20	20	22	20	16	19	19
BOD	11	45	38	10a/	—	23.5a/	10a/	21.6
BOD_C	4.5a/	7	7	8.5a/	7	4.5	6.5	6.4
TOC	12	13	17	19	19	17	16	16.14
NH_3	24.7	24.4	24.8	30.1	29	30	29.2	27.46
NO_2	.092	.063	.06	.32	.065	.12	.11	.1186
NO_3	35.9	36.5	36.4	34.9	40.2	40.1	43.8	38.26
TKN	19.2	31.9	25.5	29.8	20.1	22.1	—	24.77
TPO_4	—	—	—	—	—	—	—	—
OPO_4	—	—	—	—	—	—	—	—
Alk	3	1	1	14	1	5	2	3.857
pH	5.4	4.7	4.7	6.4	5.3	5.8	5.1	5.343
Fe	0.022	0.981	0.581	0.581	0.291	0.254	0.254	0.441

a/= Estimated from relationship BOD_5 = 0.67 COD-6.5

b/= Estimated from 1.15 mg COD/mgSS

TABLE 22. SUNSET BAY

Field Data Sheet

Date	Influent			Aeration				Effluent			
	Temp.	pH	Time	Temp.	pH	%Solids	D.O.	Temp.	pH	Totalizer gallons	Air Temp.
June 14	17°C	6.7	1300	13°C	5.2	4	4.8	13°C	5.8	3730777	18°C
June 15	16°C	6.9	1330	13°C	5.5	3	4.2	13°C	5.9	3745027	21°C
June 16	16°C	6.4	1400	14°C	5.1	3	4.5	13°C	5.7	3757100	13°C
June 17	16°C	6.6	1430	13°C	5.3	3	4.7	13°C	5.8	3771673	14°C
June 18	14°C	6.8	1330	13°C	5.4	5	4.0	13°C	6.0	3782499	12°C
June 19	15°C	6.8	1330	14°C	5.3	3	4.4	14°C	5.9	3795665	14°C
June 20	16°C	6.6	1335	14°C	5.1	3	4.7	14°C	5.8	3808211	14°C

TABLE 23. BULLARDS BEACH

FIELD DATA SHEET

Date	Influent			Aeration			Effluent			Air Temp. °C
	Temp °C	pH	Time	pH	%Solids	D.O.	Temp. °C	pH	Cl_2 Resid. mg/l	
6/14/68	15°	7.8	0900	5.4	7	3.7	16°	5.9	.20	15°
6/15/68	15°	7.4	0910	5.6	5	3.3	17°	6.1	.22	15°
6/16/68	15°	7.2	0930	5.3	3	3.0	16°	5.8	.21	15°
6/17/68	15°	7.6	0920	5.5	8	3.6	16°	5.7	.24	15°
6/18/68	15°	7.7	0906	5.6	5	3.5	14°	5.9	.21	14°
6/19/68	15°	7.5	0900	5.6	10	3.6	15°	5.8	.22	16°
6/20/68	15°	7.7	0905	5.5	9	3.6	16°	5.8	.22	13°

TABLE 24. AVERAGE COD ORGANIC LOADING AND EFFICIENCY

Area	Date	Average COD Loading lbCOD/lbMLVSS-day (Adjusted to 20°C)	Average COD Removal Efficiency	
			Total	Centrifuged
Timberline Lodge	1/21-29	0.084	72.5	92.1
	5/10-13	0.051	70.4	87.3
Crystal Mountain	2/11-19	0.125	77.3	90.6
	3/08/12	0.138	56.2	83.6
	4/26-29	0.049	70.0	92.0
Bullards Beach	6/14-20	0.126	76.0	89.0
Sunset Bay	6/14-20	0.245	78.2	90.0